NASA Scientific Data Purchase
Laboratory Characterization of Positive Systems ADAR 5500 Sensor

SN4 Report

Prepared for

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September 20, 2000

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Executive Summary

Introduction

This report summarizes the laboratory characterization of the Positive Systems ADAR 5500 SN4 multi-spectral imager measured during the period of April 10-11, 2000 in the NASA CRSP Commercial Instrumentation Validation Laboratory (CIVL). This characterization is one component of the NASA Scientific Data Purchase (SDP) validation and verification process. A complete characterization will require analysis of airborne data. The spectral, radiometric, and spatial characteristics of this system were measured and compared with the product data specifications as defined in the SDP contract. These results are summarized in the specification compliance matrices in this summary.

A complete description of the system, the SDP product specification and the sensor laboratory characterization is provided in the body of the main report.

Spectral Characterization

The ADAR 5500 consists of four boresighted spectrally filtered digital cameras model DCS-420. The cameras are built around the KODAK P/N KAF1600 1024x1536 pixel silicon CCD array digital imagers with Nikon 35-mm focal length f/2.8 camera lenses. They are referred to as the blue (450-555 nm), green (525-605 nm), red 630-690 (nm) and NIR (750-860 nm) cameras, based upon the spectral filtering used for each one. The spectral characteristics are determined by the filter transmission, lens transmission and detector spectral responsivity. Unlike previous characterizations of ADAR 5500 systems the filter spectral transmittance was not measured independently. The spectral tests included only measurement of the overall system spectral response.

Spectral cut-on and cut-off edge locations, edge slopes, and out-of-band rejection characterize the system spectral response performance. Table 1 shows the spectral specification compliance matrix with the data product specification.

Table 1. System spectral specification compliance matrix (SN4).

Spectral Band	Specification (nm)	Measured Edge (nm)	Measured Slope (%/nm)	Out-of-band Rejection	Comments
Specification	± 10 nm		>1% / nm	<5%	
Blue	450	458	1.1	<5%	
	515	516	10.5		
Green	525	531	1.5	<5%	
	605	604	9.1		
Red	630	636	5.8	<5%	
	690	690	7.7		
NIR	750	729	3.7	<5%	
	860	[illegible]	0.8		

Green	Meets specifications
Yellow	Unresolved at this time
[illegible]	Does not meet specifications

Radiometric Characterization

The SDP radiometric data product specification includes:

- Absolute and relative radiometric accuracies, at-sensor, better than 10% and 5% respectively
- Deviation from linearity less than 5%
- Detector operability greater than 99.5% for all bands

Table 2, below, shows the radiometric specification compliance matrix. The system met all radiometric specifications.

Table 2. Radiometric specification compliance matrix. (SN4)

Spectral Band	Absolute	Relative	Linearity	Detector Operab.
Spec.	<10%	<5%	<5%	>99.5%
Blue	2-4%	<2%	<5% Deviation	99.9%
Green	2-4%	<2%	<5% Deviation	99.9%
Red	2-4%	<2%	<5% Deviation	99.9%
NIR	2-4%	<2%	<5% Deviation	99.9%

Green	Meets specifications
Yellow	Unresolved at this time
[illegible]	Does not meet specifications

Spatial Characterization

The spatial data product specification includes both MTF and SNR requirements that are defined as:

- The MTF of the system must be greater than 0.2 at Nyquist.
- SNR >90 for zero spatial frequency and a standard scene of 20% reflectance and a Mid Lattitude Summer illuminated scene.
- SNR >10 for a 2:1 target to background ratio at Nyquist.

A series of tests were performed with SN4 as a method for determining best focus for the spatial tests. Edge target images were recorded as focus was varied over a range of settings. Each set of images at each different focus setting was analyzed to determine MTF at Nyquist and the half-width of the Point Spread Function (PSF) in GSD units. At the conclusion of the spatial tests the focus of the different cameras was returned to the setting yielding "best focus" analysis results.

Table 3 shows the spatial specification compliance matrix.

Table 3. Spatial specification compliance matrix (SN4).

Spectral Band	MTF @ Nyquist	SNR @ Zero Spatial Frequency	SNR at Nyquist for Standard Scene	Comments
Specification	>0.2	>70	>10	
Blue	0.25	183	46	
Green	0.20	169	34	
Red	0.20	86	17	
NIR	[illegible]	82	12	

Green	Meets specifications
Yellow	Unresolved at this time
[illegible]	Does not meet specifications

Summary

In summary, The ADAR 5500 system, SN4, does not meet data product specification for:

- The long wave cutoff of the NIR channel
- MTF at Nyquist for the NIR channel
- SNR at zero spatial frequency for the red and NIR channels
- SNR at Nyquist for standard Scene for the NIR channel

Note that all radiometric specifications were met.

1.0 Introduction: ADAR 5500 Characterization

This report presents the results of the tests performed by NASA's Commercial Remote Sensing Program Office (CRSPO) at the John C. Stennis Space Center. The CRSPO's Commercial Instrument Validation Laboratory performed testing for the Phase II NASA Scientific Data Purchase (SDP) on the Positive Systems Airborne Data Acquisition and Registration (ADAR) 5500 SN4 multispectral, digital aerial sensor. The information provided will help Positive Systems deliver better products, and investigators will be better able to quantify uncertainties resulting from analysis of these products. The report is designed to be self-contained with a large number of appendices containing supporting information. The report focuses on the characterization of the spectral, radiometric, and spatial properties of this system. The tests described and results presented are for a characterization of the SN4 system performed during the time of April 10-11, 2000.

1.1 Background

On May 23, 1997, NASA RFO No.13-SSC-O-97-21 announced the beginning of Phase I of the Earth Science Enterprise (ESE) Scientific Data Purchase program. This Request for Offers solicited proposals for remotely sensed data sets that would provide critical new science measurements or more cost-effective ways of performing ESE research. In their proposals, the data providers were to supply information on price, data validation, data rights, and applicability to the five ESE science research themes. Four of the five ESE science themes addressed by SDP are as follows:

- Land-Cover and Land-Use Change Research
- Seasonal-to-Interannual Climate Variability and Prediction
- Natural Hazards Research and Applications
- Long-Term Climate: Natural Variability and Change Research

Eighteen (18) companies proposed under Phase I and were evaluated based on the degree to which the offered data met the science, business, and performance requirements of the solicitation. Ten (10) companies were selected to submit prototypical data sets and products for Phase I evaluation.

The goal of Phase I was to evaluate prototypical data sets and to decide which of those data sets would be purchased in Phase II for the ESE research community. A wide variety of sensor types, data types, resolutions, physical parameters, and processing levels were offered. Some of the data were real and some were simulated. The selection was based on an assessment of science value, technical risk, and business risk.

An independent science assessment was conducted to determine science value for each data product offered in Phase I. Five teams of academic and governmental scientists were organized around the ESE research themes and evaluated data pertaining to their area of expertise. The scientists considered variables such as data quality, science relevance, data usability, likely breadth of use, levels of collaboration, and data rights provisions. Data quality was derived from an independent Data Verification and Validation conducted by CRSPO.

Following their review, the science panels submitted recommendations to NASA on purchasing, conditions, limitation, concerns, and enhancements. Science recommendations were taken into consideration in a final NASA evaluation, and at the close of fiscal year 1998, five of these companies were approved for Phase II data purchases.

Positive Systems, Inc., of Whitefish, Montana, which can provide 1-meter multispectral imagery, image mosaics, and collateral ground truth data, was awarded a Phase II contract. The imagery is captured with the ADAR 5500 sensor in visible and near-infrared wavelengths nearly matching the first four bands of Landsat. Radiometric resolutions of 8-bit imagery and mosaics referenced to national map accuracy standards for 1:24,000 scale data are offered. A 12-bit ADAR System will be available in the year 2000 and may be tasked for missions flown by other vendors. In addition to providing high-resolution detail on land use and land cover, these Positive Systems data sets and products will be useful for ground calibration and cross-sensor comparisons.

1.2 Technical Description of ADAR 5500

Below we present a top-level technical description of the ADAR 5500 System. A comprehensive description is provided in Appendix A. The ADAR System 5500 consists of three primary units: a camera housing, an operator console, and a power and storage unit (Figure 1, below).

The camera housing, which is designed for direct placement over the aircraft camera port, houses the digital sensors, the targeting camera, and the electronic distribution board. It incorporates manual adjustments for aircraft movement (roll and pitch +/- 5 degrees, crab angle +/- 15 degrees). The ADAR 5500 consists of four boresighted spectrally filtered digital cameras, model DCS-420. The cameras are built around the KODAK P/N KAF1600 1024x1536 pixel silicon charge coupled device (CCD) array digital imagers with Nikon 35-mm focal length f/2.8 camera lenses. Each camera is synchronously recorded with 8 bits for each pixel.

Figure 1. ADAR 5500 camera head and control electronics.

The operator console is a workstation class, RISC-based, multiprocessing computer with 64 MB of random access memory. The ADAR Flight Operations System software is resident on the internal hard drive. System functionality is controlled from the keyboard and color, active-matrix liquid crystal display via an industry standard graphical user interface.

The power and storage unit includes the power supplies to convert aircraft power at 12 or 24 volts for system use, removable hard drives for image storage, and the 8 mm tape drive for post-flight image transfer.

Figure 2 shows a schematic of the system.

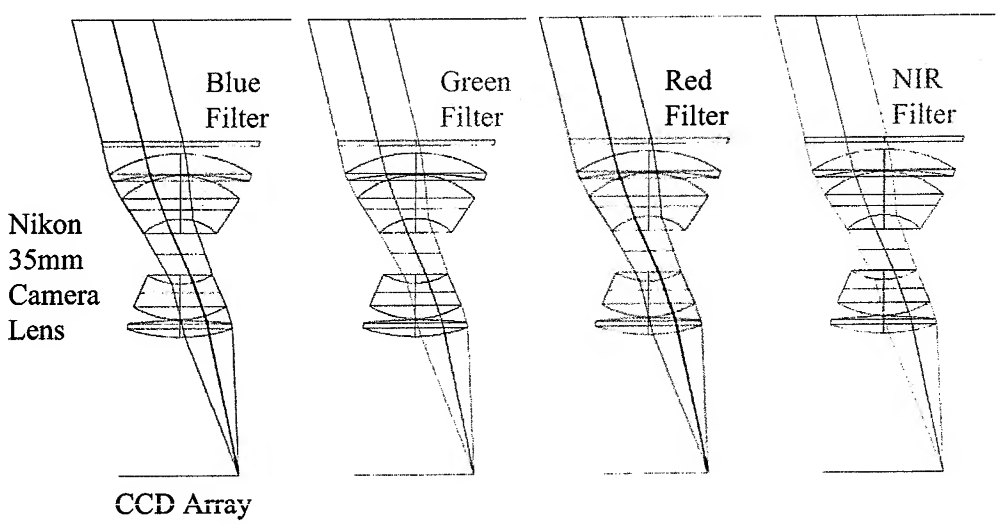


Figure 2. Four boresighted (multispectral) cameras of the ADAR 5500.

2.0 Data Product Specifications

Data product specifications from which sensor requirements were developed are shown in Table 4. This data product specification is for the data from airborne imaging systems. Although several of these quantities can be characterized in the laboratory, they need to be verified in flight. As can be seen in Table 4 some items are characterized only in the laboratory or in a functional flight test. A functional flight test is one in which calibration targets are provided. Further discussion of these issues is covered in later sections. For clarity we have provided explanations of some of the data specifications in addition to the table.

Table 4. Data product specifications.

Item	Specification	Verification	
		Lab	Functional (in flight)
Post Flight Correction	– Spectral co-registration to within 1 pixel @ 90% within the project area – Correction for lens vignetting effects – Radiometric adjustment for sensor non-uniformities – Dark current subtraction: 8-bit Subtract mean dark current value	* * *	X X X X
Spectral Band Information	– Spectral Band Pass (blue) 450-515 nm – Spectral Band Pass (green) 525-605 nm – Spectral Band Pass (red) 630-690 nm – Spectral Band Pass (NIR) 750-860 nm	X X X X	
Spectral Band Pass Accuracy	– Band edge points at 50% peak response shall be within ± 15 nm of the normal values – Slope through the 50% point shall be at least 15% per 20 nm – Out-of-band filter response must be less than 5% of the total integrated transmittance within 5% of the transmission points of the band.	X X X	
Radiometric Quantization	8-bits per spectral channel	X	X

Table continued on following page.

Item	Specification	Verification	
		Lab	Functional (in flight)
Radiometric Accuracy Stability	– Absolute Radiometric Accuracy to within ± 10%. – Relative Radiometric Accuracy to within ± 5%. – Linearity to within ± 5.0% of full scale exposure over the entire imaging exposure dynamic range – Requirements on banding, streaking, failed and non-calibrated detectors: 99.5% of all the detectors should be within ± 5% or ± 1 DN of the mean dark counts of all focal plane array detectors; 99.5% of all the detectors should be within ± 5% of the gain coefficients of all focal plane array detectors.	* * X X N/A	X X X X N/A
Spatial Resolution and Image Quality (at all field angles)	– At zero spatial frequency, for all spectral bands, the SNR will be greater than 70 for a Lambertian surface with 20% reflectance, illuminated at solar zenith angle of 30 degrees	X	X
Image File Format	– ERDAS ".lan" or other formats	X	X
Metadata File Format	– Intermediate level ECS Metadata Standard	X	X
Sidelap and Endlap	– 35% and 35%		X
Percent Cloud Cover	– less than 10% across full data set		X
Absolute Geolocation Accuracy	– Frame center point coordinate referenced to ± 100 meters in metadata listing		X
Resampling Algorithm	– Nearest Neighbor	X	X
Collateral Documentation	– Customer Data Sheet (format plan, flight log, sensor, GPS, post processing) – Sensor calibration report – Ground calibration report – Instrument specifications – Reports on Aircraft GPS – Frame index map – Field data descriptions	N/A X N/A X N/A N/A N/A	X X X X X X X

**** Calibration files produced in lab; need to be verified in-flight***

The band-to-band registration specification states the bands are to be registered to better than 0.5 pixels. This specification is illustrated in Figure 3, where the colored disks represent each band and the centroid is the distance between bands.

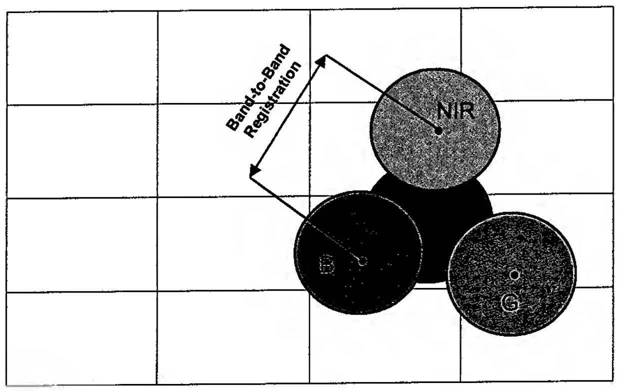


Figure 3. Band-to-band registration.

Of all the properties, the spectral characteristics of the sensor are among the more important in determining the overall performance of the system. The spectral characteristics are determined by the filter transmission, lens transmission, and detector spectral responsivity. Spectral cut-on and cut-off edge locations, edge slopes, and out-of-band rejection characterize the spectral performance. The system response has been specified to be Landsat-like, but only for the first four bands. The bands are referred to as the blue (450-515 nm), green (525-605 nm), red (630-690 nm), and near-infrared (NIR) (750-860 nm) bands. These bands are not exactly Landsat bands, but they are sufficiently close to perform most Landsat-like applications. They are closer in specification to the next-generation, high-spatial-resolution satellite systems. For example, the NIR band red edge was pushed toward the blue to avoid the atmospheric water vapor absorption near 940 nm. The spectral response is defined by its band-edge points, slopes, and out-of-band transmittance as shown in Figure 4.

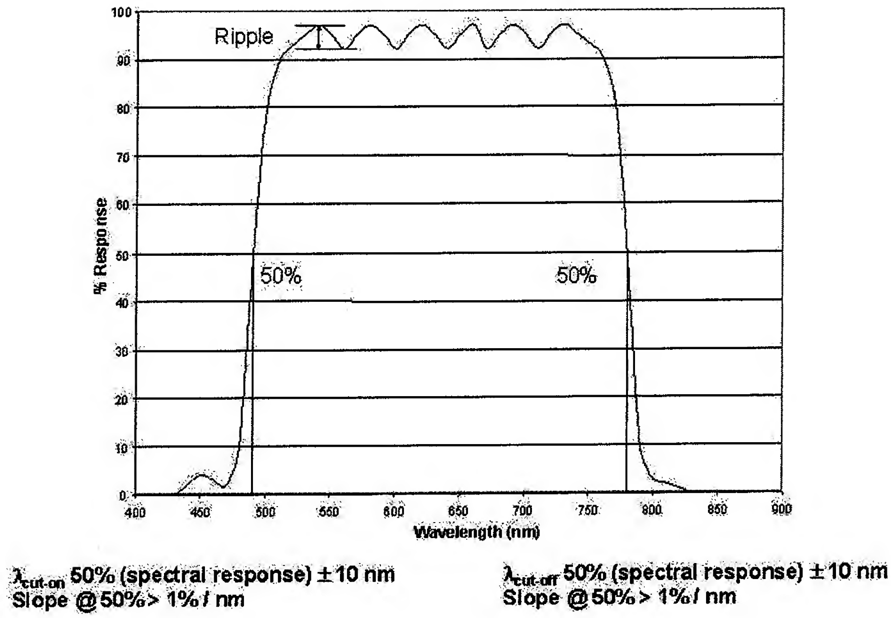


Figure 4. System spectral response.

The radiometric accuracy at the sensor is specified to be ± 10% absolute and ± 5% relative between bands. As part of the overall radiometric accuracy, the response of the system was specified to be linear to ± 5%. This linearity specification is illustrated in Figure 5.

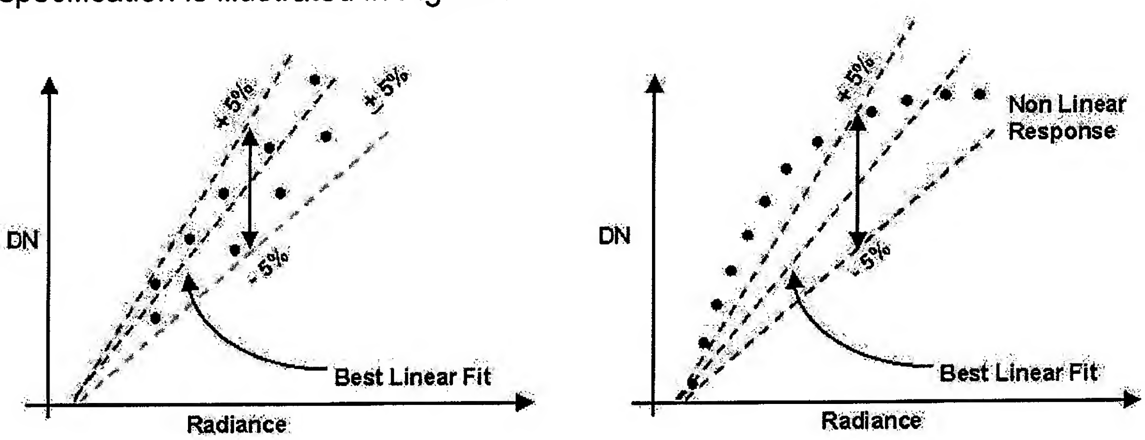


Figure 5. Linear and non-linear response to input radiance.

Another specification related to radiometric response is detector operability. Since array-based imaging systems routinely have well over a million detectors,

the number of “bad” pixels could be significant. A “bad” pixel is defined as one with dark current or responsivity more than ± 5% different from the mean values for the array. The array is to have no more than 0.5% of the total number of pixels that are “bad”.

The spatial resolution is determined by the signal-to-noise ratio (SNR) and the modulation transfer function (MTF) of the system. The minimum acceptable MTF is specified at Nyquist. Nyquist is defined here to be half the detector cutoff spatial frequency. Figure 6 illustrates the definitions associated with this specification. The minimum SNR is specified for both zero spatial frequency and at Nyquist. These specifications apply to airborne data.

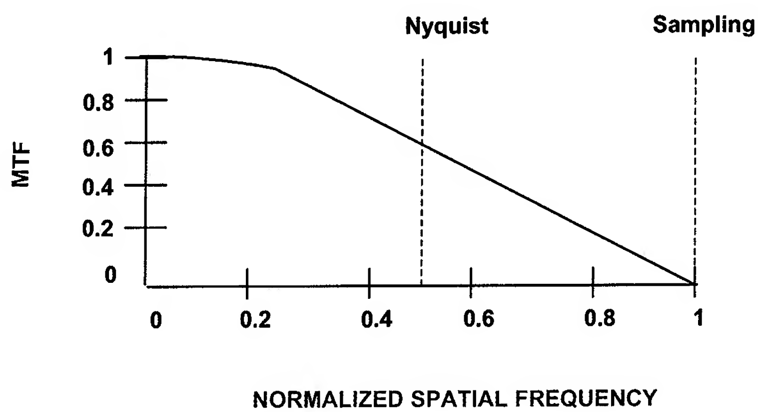


Figure 6. Normalized spatial frequency.

3.0 System Characterization

The system is characterized and data processing is performed in the following order:

1. Spectral
2. Radiometric
3. Spatial

This order is chosen because the spectral response is a necessary component to evaluate the radiometric response, and the radiometric response is necessary for determining the MTF. In practice, however, self-consistency is checked for between the different types of data sets. For each measurement, the methodology, procedures, and results are discussed. The overall equipment list for the measurements is shown in Appendix B.

3.1 Spectral Characterization

3.1.1 Introduction

Of all the properties, the spectral characteristics of the sensor are among the more important in determining the overall performance of the system. The spectral characteristics are determined by the filter transmission, lens transmission, and detector spectral responsivity. Spectral cut-on and cut-off edge locations, edge slopes, and out-of-band transmission characterize the spectral response.

Table 5 defines the blue, green, red, and NIR bands. There are some slight differences between Landsat and the ADAR 5500 spectral filters to avoid atmospheric water vapor absorption features and to be similar to the next-generation, high-spatial-resolution satellite imagers.

Table 5. Spectral band definitions.

Spectral Band	Bandpass
Blue	450-515 nm
Green	525-605 nm
Red	630-690 nm
NIR	750-860 nm

3.1.2 Methodology

Techniques were developed to measure overall system spectral response. In addition, the filter manufacturer provided the spectral transmittance data of the filters. This data is provided in Appendix D. Alternate approaches to the characterization of system spectral response are discussed in Appendix D. Appendix E has the typical quantum efficiency curves for the Kodak KAF -1600 CCD as well as other pertinent information on the CCD array. Actual measurement of the lens contribution to overall system spectral response was not performed.

Direct system spectral response measurements were made for each of the four spectral bands of the sensor in a separate experiment. For each of the bands, a series of images was recorded while the sensor was imaging a narrow-bandwidth light source formed by a 4" diameter integrating sphere externally illuminated by the output from an Acton 0.5 meter monochromator (See Appendix I). Figure 7 shows the test setup. The integrating sphere's output was independently monitored by a calibrated spectroradiometer through a fiber optic probe (See Appendix J).

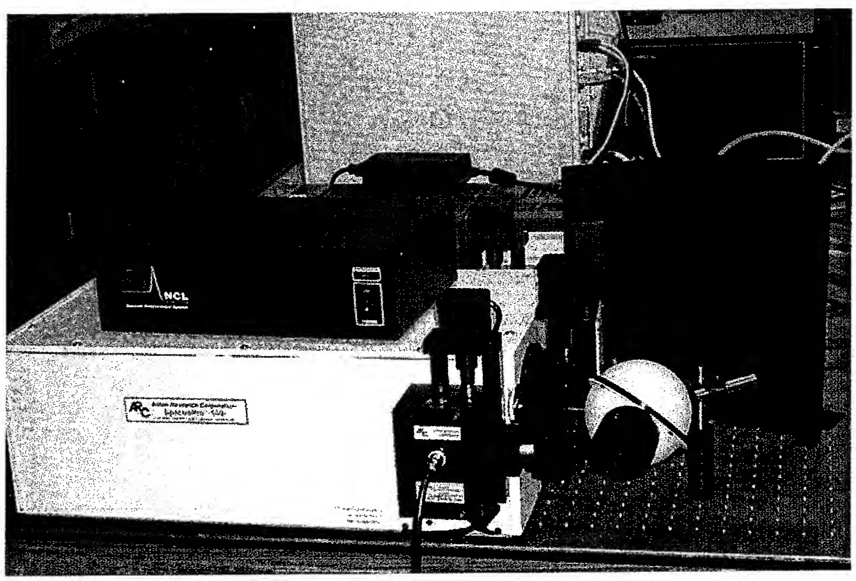


Figure 7. Test setup for overall system spectral response.

Five images were collected at each wavelength, and five dark images were also recorded for each spectral scan.

3.1.3 Results / Analysis

Because the output port of the integrating sphere did not fill the entire field-of-view of the sensor, a uniformly illuminated region of interest (ROI) of 301 by 301 pixels was selected from each image. Location of the ROI, which was used to calculate an average digital number (DN), was the same for all the images collected for a given band. The overall spectral response as a function of field angle should be fairly flat because of the relatively constant spectral shape of the filters shown in Appendix D.

After subtraction of mean dark counts, the average values were corrected for differences in illumination at various wavelength settings by dividing them by the integrated radiance as measured by the calibrated spectroradiometer. The spectral response functions were normalized to their maximum values. To determine wavelengths of the spectral band edges, points on the normalized curve with response of 50% were found by linear interpolation between the closest samples. The same samples were used to measure edge slopes. Measured characteristics of the spectral bands are compared with requirements in Table 6.

Table 6. System spectral specification compliance matrix (SN4).

Spectral Band	Specification (nm)	Measured Edge (nm)	Measured Slope (%/nm)	Out-of-band Transmission	**Comments**
Specification	± 10 nm		>.75% / nm	<5%	
Blue	450	458	1.1	<5%	
	515	516	10.5		
Green	525	531	1.5	<5%	
	605	604	9.1		
Red	630	636	5.8	<5%	
	690	690	7.7		
NIR	750	729	3.7	<5%	
	860		0.8		

Green	Meets specifications
Yellow	Unresolved at this time
	Does not meet specifications

Figure 8 shows the normalized spectral response for each of the bands. The NIR band short wavelength edge appears out of specification. However, given the uncertainty in the measurement (about 10 nm) it was not identified as out of

specification. The long wave edge, however, is clearly out of specification. We believe this could be due to the transmission of the NIR lens. The slope of the long wave edge also appears out of specification. Again, the uncertainty of the measured value is such that it was not identified as out of specification. The shape seen in the NIR spectral response curve is felt to be due to a combination of reduced lens transmission and diminishing detector response at longer wavelengths.

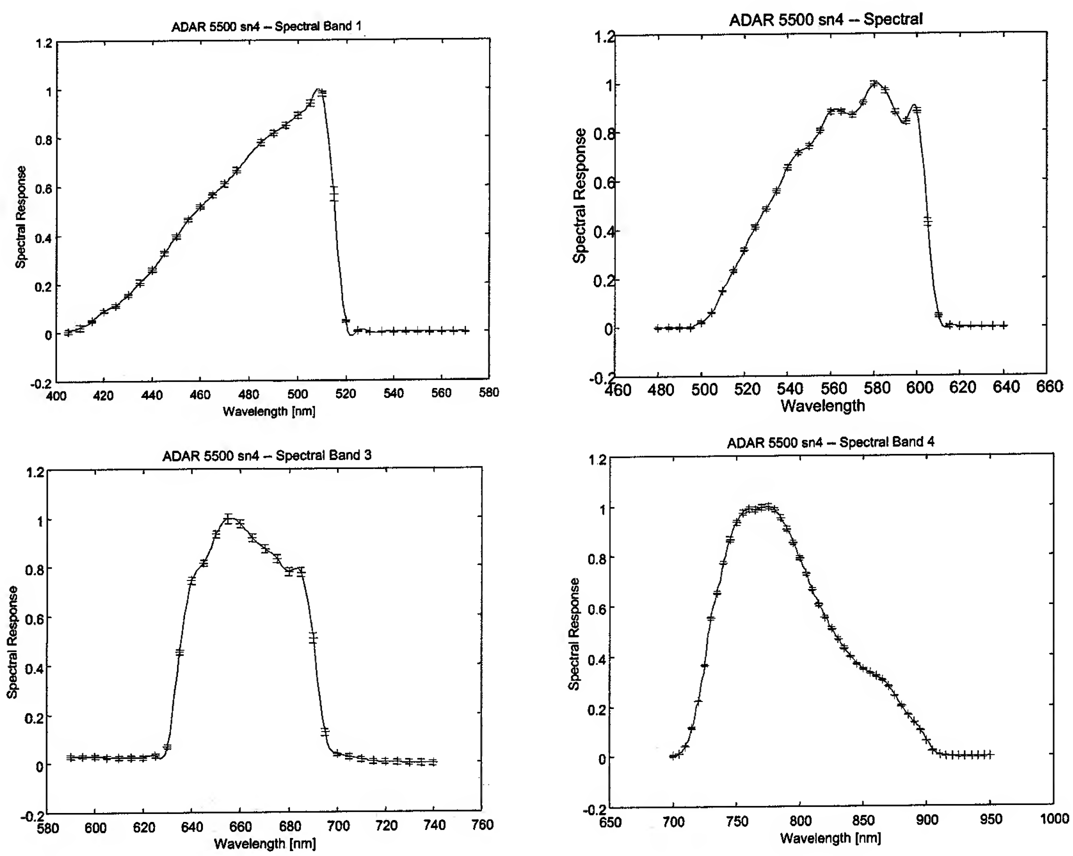


Figure 8. Normalized spectral response functions of the ADAR 5500 SN4 sensor. Measured points are shown with error bars. Lines show spline interpolation between the points.

3.2 Radiometric Characterization

3.2.1 Introduction

Radiometric characterization of the system includes absolute and relative radiometric calibration, SNR estimation, and linearity. SNR is determined using the radiometric data but is discussed in the next section to be consistent with the data specifications.

The SDP radiometric product data specification includes the following:

- Absolute and relative radiometric accuracies better than 10% and 5% respectively
- Deviation from linearity less than 5%
- Detector operability greater than 99.5%

3.2.2 Methodology

For radiometric measurements, the sensor head, with all four cameras mounted in the flight configuration, was positioned on a wheeled support with the lens of the camera under test centered on the sphere exit port (see Figure 9). The optical axis of the camera was set to be normal to the exit port plane. For the measurements, we used the Optronics OL series 462 12" integrating sphere and recorded the aperture setting and exposure time. The integrating sphere is designed to produce a National Institute of Standards and Technology traceable Lambertian source with an overall maximum of uncertainty less than 4%. The exposure log sheet is tabulated in Appendix F and the integrating sphere details are discussed in Appendix G.

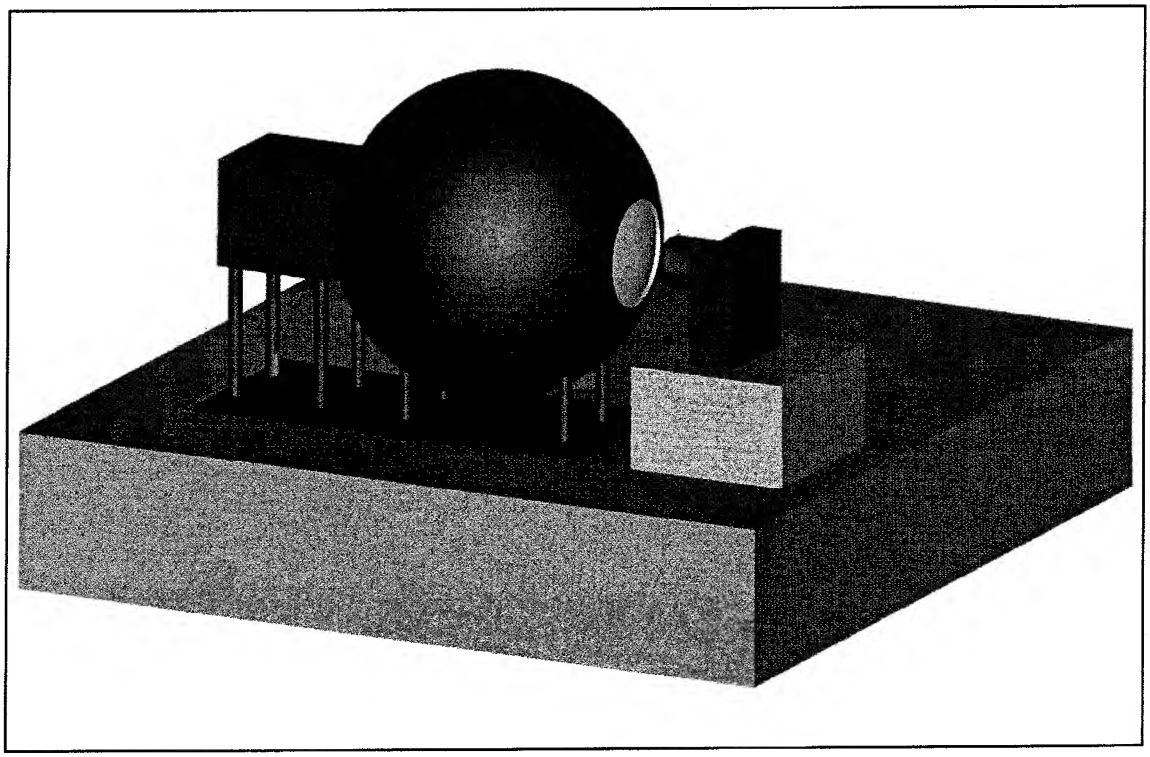


Figure 9. Radiometric, signal-to-noise, and linearity test setup.

3.2.3 Procedure

The following was performed on SN4 camera heads:

- Recorded 10 dark frames (each capped camera separately)
- Short exposure times (typical)
- Long exposure times
- Recorded 10 light frames, each camera, at each of the following sphere settings:
  - To produce near-full-scale (NFS) DN of about 230 in the camera under test, with f-number and integration time set for typical mission settings
  - ~ 75% NFS
  - ~ 50% NFS
  - ~ 25% NFS

At the end of radiometric data measurement for each system, several frames were recorded at different exposure times to determine linearity with integration time. The number of frames was chosen to provide a balance between having enough frames for good statistics, the amount of time it takes to record the data, and storage requirements.

3.2.4 Results / Analysis

3.2.4.1 Uniformity of detector arrays

To remove effects of temporal noise, 10 dark images were collected for each of the detector arrays. A histogram of DN's was calculated for each image, and an average histogram was found for each band. The average histograms of darkcount numbers are shown in Figure 10.

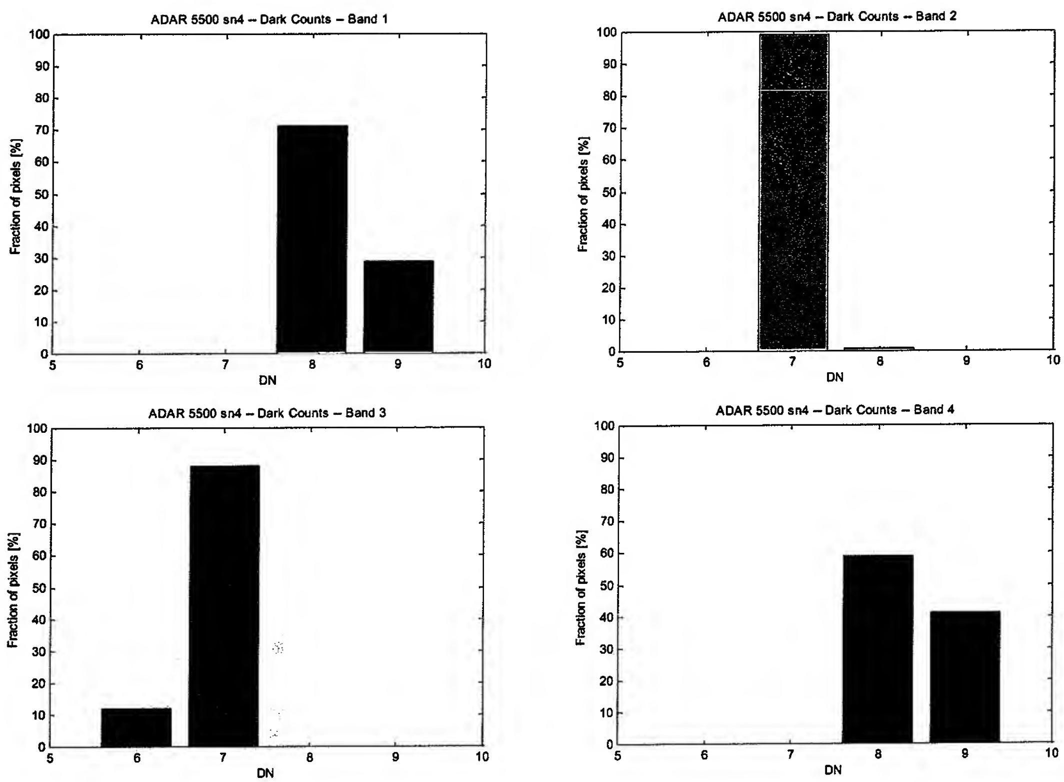


Figure 10. Histograms of dark count numbers of the ADAR 5500 SN4 sensor.

To analyze operability, a mean dark DN was calculated for each detector array, and pixels with the number of dark counts different from the mean by less than 5% from the mean value were counted. Results of the analysis are shown in Table 7. Operability is to be 99.5% or better.

Table 7. Uniformity of detector arrays of the ADAR 5500 SN4.

Spectral Band	Exposure time(s)	Dark DN	Operability (%)
Blue	1/400	8.29 ± 0.19	99.9
Green	1/1000	7.01 ± 0.04	99.9
Red	1/1000	6.88 ± 0.20	99.9
NIR	1/1000	8.41 ± 0.23	99.9

3.2.4.2 Radiometric linearity

Radiometric linearity was evaluated in two separate tests. In the first test, linearity of the dependence of *DN*'s on exposure time was analyzed for each of the spectral bands. The range of exposure times used in the test extended from 1/2000 s to 1/60 s for all bands. Five images were collected with a given exposure time, and average *DN*'s were found from both images over a uniformly-illuminated region of interest (ROI) of 301 by 301 pixels. Location of

the ROI was the same in all the images. Results of the exposure time tests are displayed in Figure 12. Dependence of average *DN*'s on exposure time is clearly linear within the 5% tolerance.

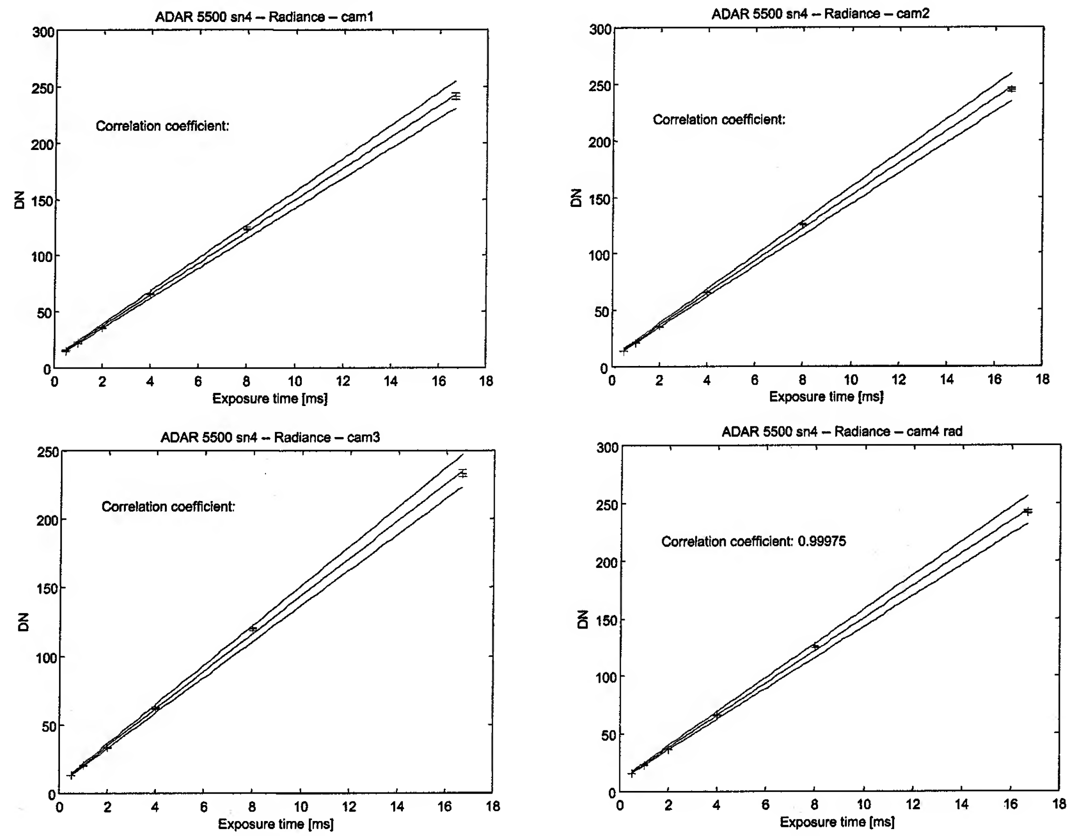


Figure 11. Dependence of average *DN*'s on exposure time for the ADAR 5500 SN4 sensor. Measured points are shown with error bars. Solid lines show linear interpolation between the points. Dash lines show the 5% tolerance.

In the second test, a radiometric calibration of the sensor was performed for each of the spectral bands. In consecutive measurements, an integrating sphere set to one of four different radiance levels (including a dark one) illuminated the sensor. Five images were collected at each radiance level using exposure time of 1/400, 1/1000, 1/1000, and 1/1000 s for the Blue, Green, Red, and NIR band, respectively. The five frames were averaged to remove effects of temporal noise (photon, detector, and electronics). For each pixel separately, dependence of the average *DN*'s on in-band radiance (L_i) from the integrating sphere was analyzed and fitted with a linear function:

$$L_i = c_1\bar{D}N + c_2$$

where c_1 and c_2 are the calibration coefficients. Values of the in-band radiance were calculated for each band by numerical integration using the following formula:

$$L_i = \frac{\int R_i(\lambda)L(\lambda)d\lambda}{\int R_i(\lambda)d\lambda}$$

where $R_i(\lambda)$ is the spectral response of the band, measured during the spectral tests, and $L(\lambda)$ is the spectral radiance from the calibrated integrating sphere, proportionally adjusted for the setting of the sphere. Both multiplication and integration were performed with spline interpolation of the functions to the sampling interval of 1 nm over the spectral range from 400 to 950 nm. Figure 12 shows examples of dependence of *DN*'s on in-band radiance for selected pixels from all the spectral bands of the sensor (pixels with the largest uncertainty in the calibration parameters were selected). Linear radiometric calibration was found to be valid for all the pixels of the ADAR 5500 SN4 sensor.

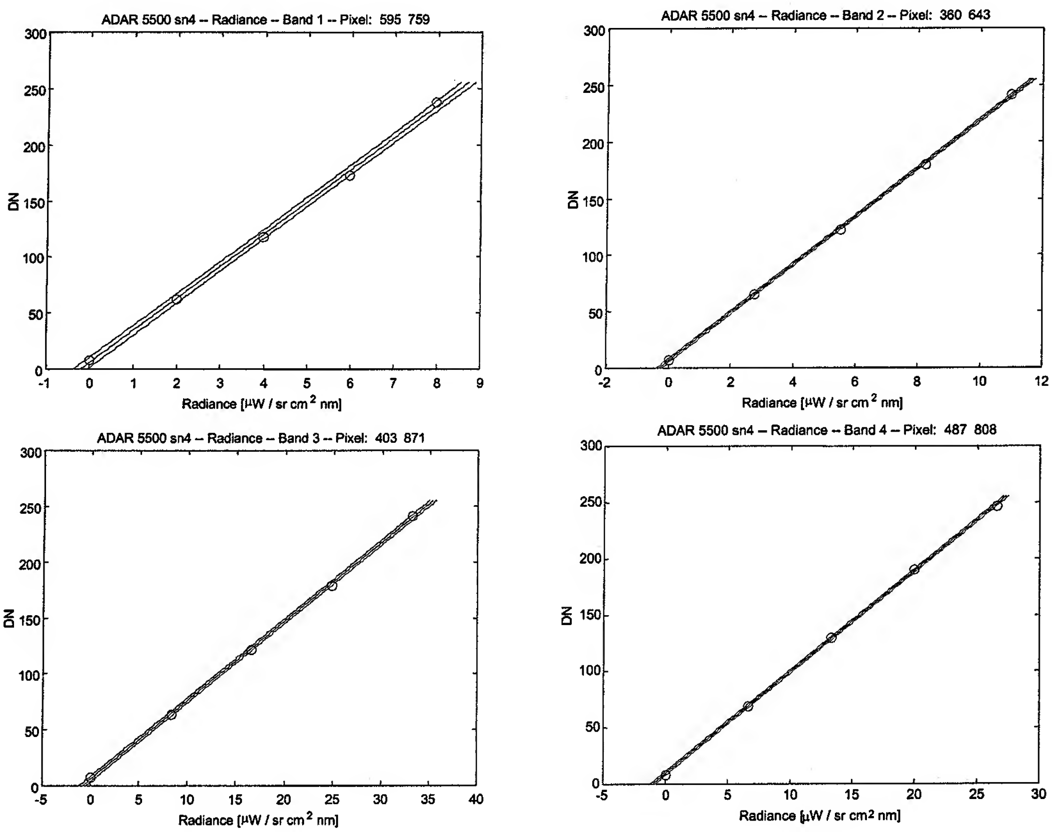


Figure 12. Dependence of average DN's on integrated in-band radiance for the ADAR 5500 SN4 sensor. Measured values are shown with circles. Solid lines display the fitted line, while dash lines show an estimation of uncertainty in the fitted line.

3.2.4.3 Compliance

The radiometric specification compliance matrix is shown in Table 8. The KODAK KAF1600 CCD digital camera baseline configuration converts 12-bit digital data to an 8-bit data set via a lookup table. For the results presented here

the look-up table was programmed for linear radiometric response. The system met all radiometric specifications.

Table 8. Radiometric specification compliance matrix (SN4).

Spectral Band	Absolute	Relative	Linearity	Detector Operab.	Comm.
Spec.	<10%	<5%	<5%	>99.5%	
Blue	2-4%	≤2%	<5% Deviation	99.9%	
Green	2-4%	<2%	<5% Deviation	99.9%	
Red	2-4%	<2%	<5% Deviation	99.9%	
NIR	2-4%	<2%	<5% Deviation	99.9%	

Green	Meets specifications
Yellow	Unresolved at this time
	Does not meet specifications

3.3 Spatial Characterization

3.3.1 Introduction

The spatial resolution is determined by the ground sample distance and point spread function (or MTF). SNR was considered in the spatial characterization part of the data product specifications, since SNR can play an important role in image quality and in the ability to resolve objects.

The spatial data product specification included both MTF and SNR requirements that were defined as follows:

- The MTF of data must be greater than 0.2 at Nyquist.
- SNR >90 for zero spatial frequency from a standard scene of 20% reflectance and a mid-latitude summer solar illuminated scene.
- SNR >10 for a 2:1 target to background ratio at Nyquist.
- SNR was estimated using radiance data from the integrating sphere.

3.3.2 Methodology

The MTF was determined by measuring the edge response and fitting the response to the point spread function. A typical, experimental setup is shown in Figure 13. The details are discussed in Appendix H.

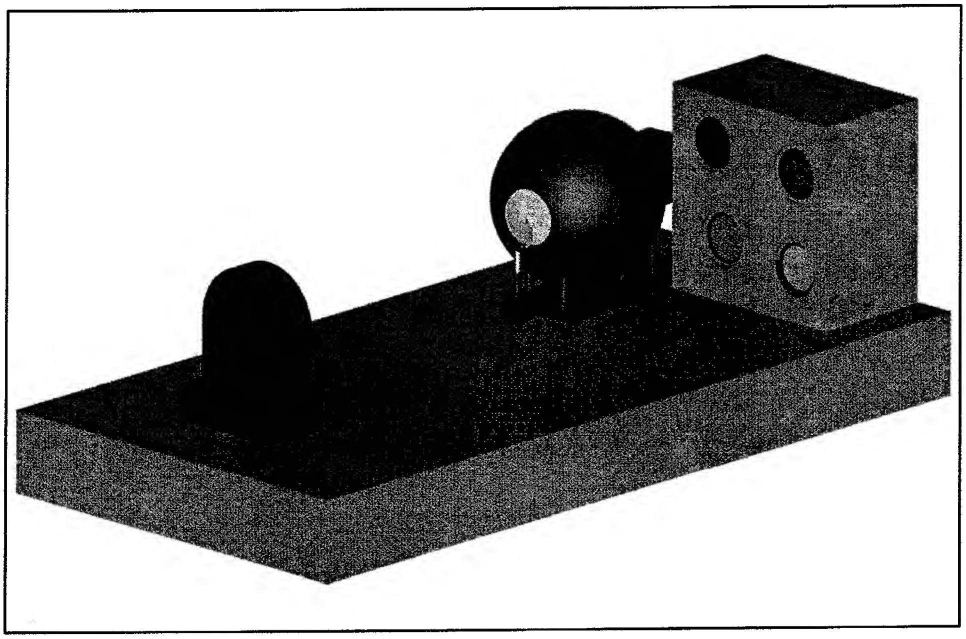


Figure 13. MTF test setup looking at the edge target in a collimator.

The spatial resolution tests were conducted indoors with an off-axis parabolic collimating mirror. The edge target was a sharp knife edge placed at the focus of the mirror and illuminated from behind by an integrating sphere whose exit port was lambertian. A line of pixels across the edge (the one with the longest regions of high and low intensity) was selected from each image and used to derive the edge response. The pixel lines crossed the edge at an angle of ~7 degrees; therefore, the spatial scale (*x*) was multiplied by the tangent of the angle to take the tilt into account. In a single test session, a series of 25 images were collected by each camera separately, and a pixel line was extracted from each image.

Figure 14, below, is a fragment of an image from the blue band camera. This is typical of the data acquired.

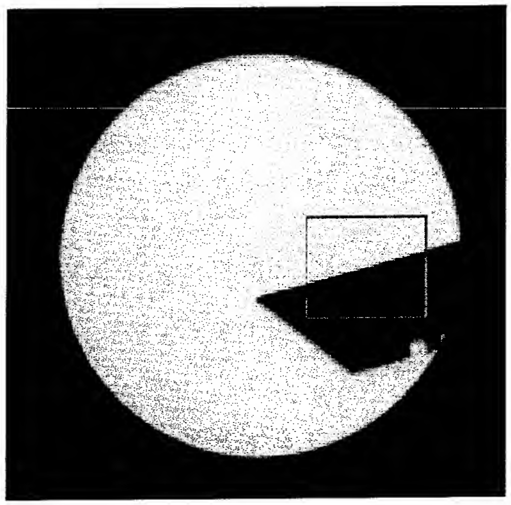


Figure 14. Fragment of a Blue-band image from tests of spatial resolution of the ADAR 5500 SN4 sensor.

3.3.3 Results / Analysis

3.3.3.1 Spatial resolution

The Full Width at Half Maximum (FWHM) of a line spread function and the MTF, are used as measures of spatial resolution of the sensor. Line spread functions $l(x)$ of the tested sensor were assumed to be well approximated by the Gaussian function:

$$l(x) = A\exp\left[-4\ln 2\left(\frac{x-x_0}{\Delta}\right)^2\right]$$

where FWHM (Δ) as well as A and x_0 are parameters. FWHM is measured with the same units as distance (x). The edge response $e(x)$ is then given by:

$$e(x) = \int_{-\infty}^{x} l(t)dt = \frac{A\Delta}{4}\sqrt{\frac{\pi}{\ln 2}}\left[1+\mathrm{sgn}(x-x_0)\mathrm{erf}\left(2\sqrt{\ln 2}\frac{|x-x_0|}{\Delta}\right)\right]$$

where sgn(x) is the signum function:

$$\operatorname{sgn}(x) = \begin{cases} 1 & \text{for } x > 0 \\ 0 & \text{for } x = 0 \\ -1 & \text{for } x < 0 \end{cases}$$

and erf(x) is the error function:

$$\operatorname{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x \exp(-t^2) dt$$

To compensate for effects of non-uniformity in the edge target illumination, and perhaps for effects of small deviations of the measured line spread functions from the Gaussian shape, a second-order polynomial was added to the edge response function, such that the measured edge response points were fitted with the following function:

$$f(x) = \frac{A\Delta}{4}\sqrt{\frac{\pi}{\ln 2}}\left[1 + \operatorname{sgn}(x - x_0)\operatorname{erf}\left(2\sqrt{\ln 2}\frac{|x - x_0|}{\Delta}\right)\right] + \alpha x^2 + \beta x + \gamma$$

where Δ, A, x_0, α, β, and γ are the fitted parameters. It was always checked if the distance-dependent contribution of the polynomial term to the overall edge response is small. Typical results from the fitting process are presented in Figure 15. The examples confirm that the measured edge response functions can be accurately fitted with the Gaussian-based function and a small polynomial correction. All the 25 lines were used to derive an average edge response, such as the ones shown in Figure 15. Results of the tests were used to calculate a mean value and standard deviation of FWHM, which became the measured resolution and its uncertainty, respectively, and are listed in Table 9.

Historically, when spatial resolution tests were repeated several times on different days, a significant variance was observed among the results. Sometimes, spatial resolution of the sensor changed even without an explicit alteration of the focus settings of the sensor lens. It should be noted that the spatial resolution of the SN4 configuration was measured during only one test on one day; therefore, the in-flight spatial resolution of the ADAR 5500 SN4 sensor might deteriorate from the laboratory values, if not controlled.

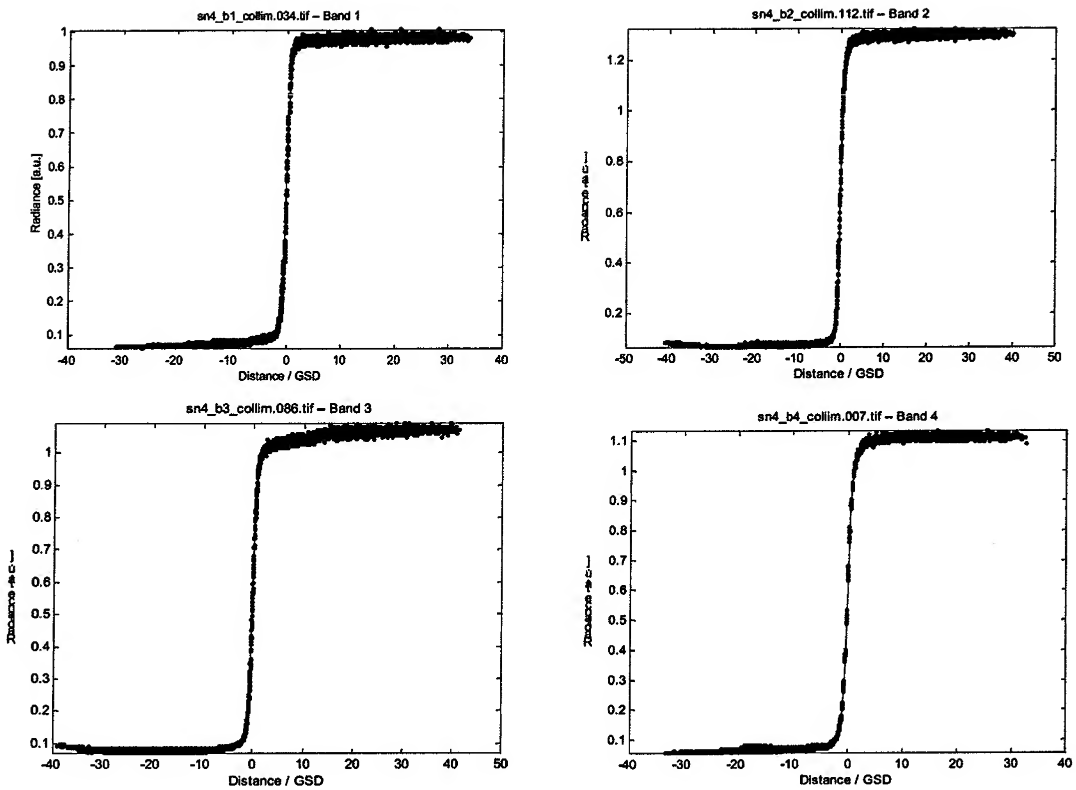


Figure 15. Examples of edge response functions obtained for the four bands of the ADAR 5500 SN4 sensor. Measured points are shown with circles. Solid lines show the overall fitted functions.

Table 9. Spatial resolution of the ADAR 5500 SN4 sensor.

Spectral Band	**FWHM / GSD**	**MTF@ Nyquist**
Blue	1.180 ± 0.005	0.25
Green	1.22 ± 0.02	0.20
Red	1.282 ± 0.005	0.20
NIR	1.36 ± 0.01	0.15

Using again the assumption of the Gaussian shape of the line-spread function, values of MTF at Nyquist frequency were calculated for each band. Calculations of the full MTF's were slightly modified by multiplying the Gaussian function by the detector MTF (the sinc function) while keeping the value of MTF at Nyquist frequency unchanged. Figure 16 shows MTF's calculated using the spatial frequency scale normalized to the frequency of the detector cut-off. Nyquist frequency is equal to 0.5 in that scale. For MTF much less than at Nyquist, the ability to determine the MTF at high spatial frequency is limited.

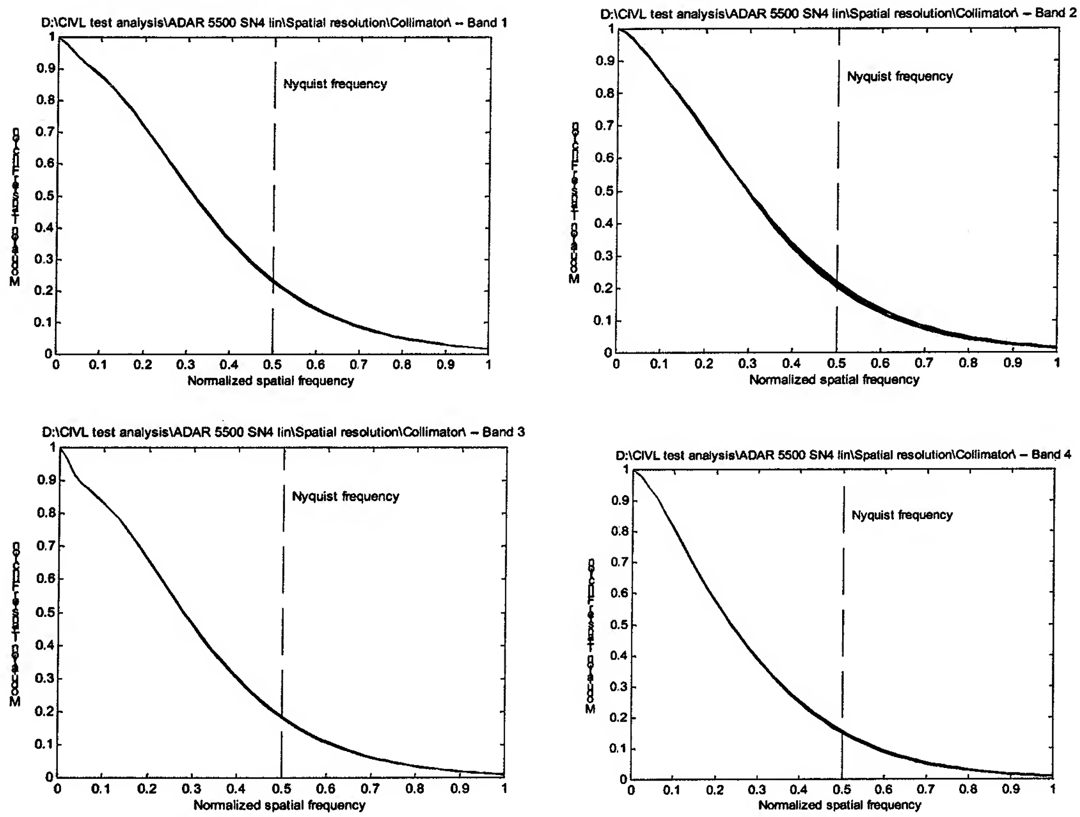


Figure 16. MTF's of the ADAR 5500 SN4 sensor derived from the laboratory tests of spatial resolution.

3.3.3.2 Signal-to-noise ratio

The radiometric calibration tests were also used to evaluate signal-to-noise ratios (*S/N*) for each of the spectral bands. At each level of illumination (in-band radiance), the five collected images were used to calculate not only mean *DN*, but also standard deviation (ΔDN) of the *DN* for each pixel. Radiometric calibration was performed on the images to produce values of radiance (L) and noise-equivalent radiance (ΔL). Those values were averaged over all the pixels and used to calculate *S/N* at given in-band radiance:

$$S/N = \frac{\langle L \rangle}{\langle \Delta L \rangle} = \frac{\langle c_1 DN + c_2 \rangle}{\langle c_1 \Delta DN \rangle}$$

The mean *S/N* values measured at four levels of radiance (including dark) were used to fit the dependence of *S/N* on radiance with the square-root formula:

$$S/N = a\sqrt{L} + b$$

where *a* and *b* are the fit parameters. Measured points and the fitted functions are shown in Figure 17. The good quality of the fit implies that performance of the sensor is photon-noise limited. The formula with the parameter values obtained for the best fit was used to calculate *S/N* for the in-band radiance generated with MODTRAN for a given scene. MODTRAN calculations were conducted for mid-latitude summer, rural atmosphere with 23-km visibility, 20% surface reflectance located at sea level, solar zenith angle of 30 degrees, and sensor altitude of 1944 meters. Figure 17 shows values of *S/N* predicted using the MODTRAN radiance.

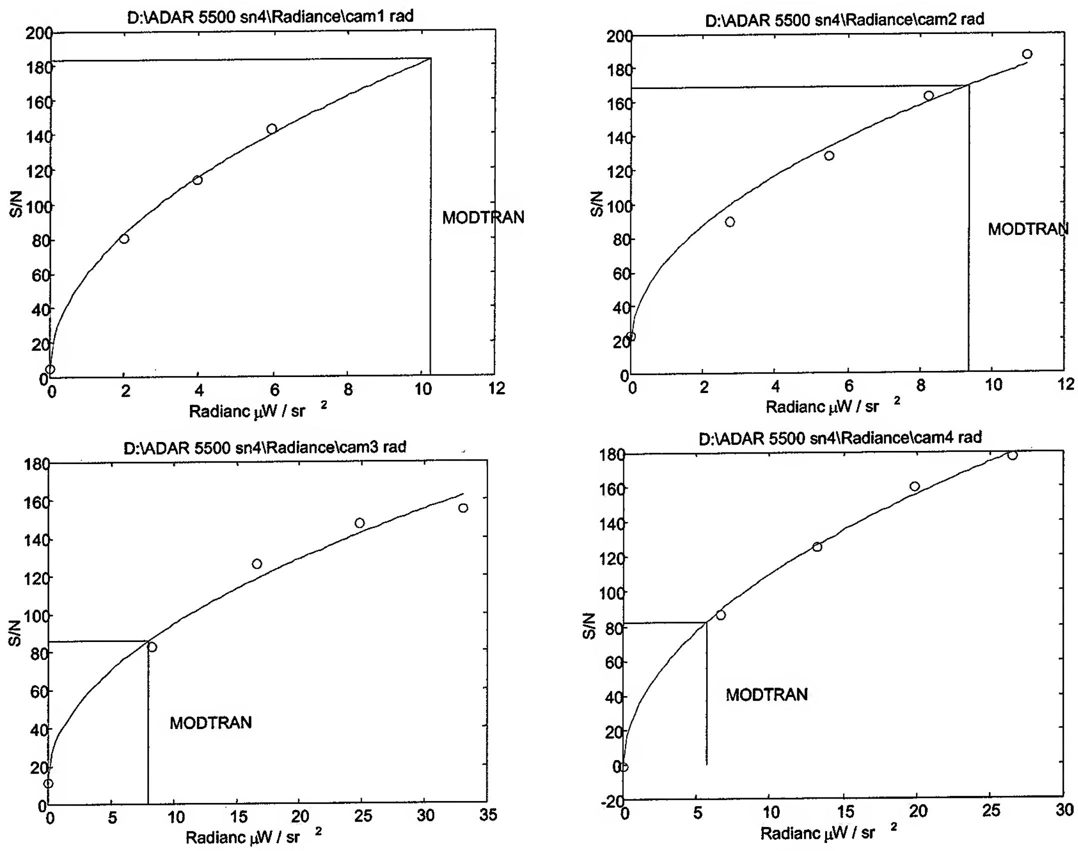


Figure 17. Temporal signal-to-noise ratios of the ADAR 5500 SN4 sensor. Measured points are shown with circles, dash lines only connect the points, and the long-dash lines show the MODTRAN-generated radiance.

Table 10 shows the SNR values estimated for the MODTRAN-generated scene.

Table 10. Signal-to-noise ratios at zero spatial frequency estimated for the ADAR 5500 SN4 sensor with the MODTRAN scene (see text).

Spectral Band	SNR Ratio
Blue	183
Green	169
Red	86
NIR	82

3.3.3.3 Compliance

Table 11 shows the spatial compliance matrix. The NIR camera was the only camera to not meet all spatial specifications.

Table 11. Spatial specification compliance matrix for SN4.

Spectral Band	MTF @ Nyquist	SNR @ Zero Spatial Frequency	SNR at Nyquist for standard scene	Comments
Specification	>0.2	>70	>10	
Blue	0.25	183	46	
Green	0.20	169	34	
Red	0.20	86	17	
NIR	[illegible]	82	12	

Green	Meets specifications
Yellow	Unresolved at this time
Red	Does not meet specifications

4.0 Conclusions / Recommendations

The ADAR 5500 system at the time of this characterization does not meet data product specification in some areas. Improvement in spatial resolution of the NIR band is now the major requirement.

Our recommendations include the following:

- Development of a method to monitor image changes in real time while setting focus
- More careful attention in setting the focus of the various cameras
- Determine optical transmission of the lens used with the NIR camera and investigate alternatives which might provide better transmission

Appendix A. ADAR 5500 System Information

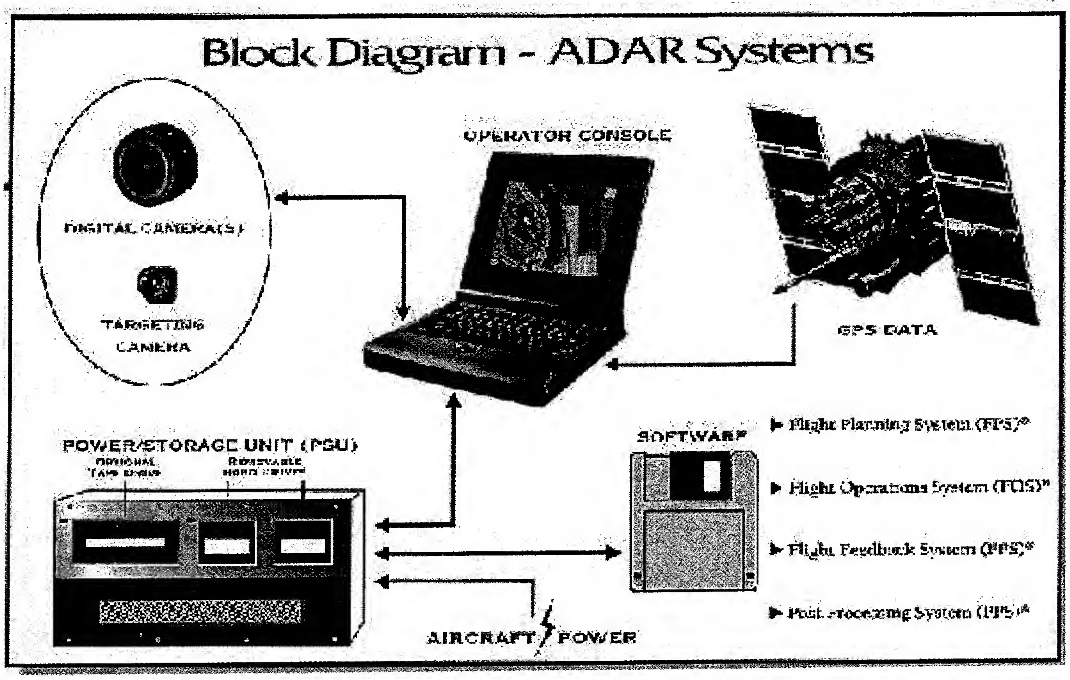


Figure 18. ADAR systems block diagram.

ADAR 5500 Standard Features

Optics and Filters

The ADAR System 5500 utilizes high grade imaging optics, to ensure spatial and spectral fidelity of the images.

Computer

The ADAR System 5500 is built around powerful RISC based computer architecture. 64 M Byte of Random Access Memory (RAM) is standard, and permits true multitasking operation. The modular system architecture permits future expansion as new features and special purpose systems are developed.

Other Standard Features

- AC External power supply,
- Rugged storage/transportation containers
- Multiple camera head capability.

ADAR Flight Operations System (FOS)

The FOS includes a comprehensive set of tools for reliable image capture and in-flight quality control and verification, including:

- Display of sensor, GPS and Targeting Camera parameters and operation.
- In-flight viewing of captured images for immediate quality control of focus and exposure parameters.
- GPS log of latitude, longitude, altitude, date & time for each image.
- Operators flight log.
- In-flight determination of targeting accuracy and image overlaps to prevent costly reflights.
- Utilities for general system management, tape writing, file management etc.

Post-Flight Processing Modules

Positive Systems has extensive ongoing development of a wide variety of post -flight processing modules for ADAR Digital Aerial Photography.

Modules included as standard equipment with the ADAR System 5500 are:

- Vignette Correction Corrects images for exposure variations due to the internal effects of sensor and optics.

- Band to Band Registration Provides automatic band co-registration for four band multispectral images.

- File Format Translators Performs conversion of the digital images to common
- image file formats, such as ERDAS (lan), Band Sequential (BSQ) and TIFF.

Sensor Description

Spatial Resolution: 50 cm to 3 meters per pixel Ground Sample Distance (GSD) Higher resolutions possible with use of rotary aircraft platform
Type: Digital charged couple devices (CCD)
Number: 4 individual bands
Format: Full frame capture, 1536 by 1024 pixels
Field of View: Across-track –22.6 degrees
Instantaneous Field of View– 0.257 mrad at Nadir
Spectral Range: 400 nm to 1000 nm (0.4 to 1 micron)
Spectral Resolution: 8 bits per band
Lenses: High quality imaging optics, 35mm, f/2.8

Bands: User selectable

Operator Console

CPU: Workstation - RISC architecture
RAM: 64 M Byte
Display: Color Active Matrix Liquid Crystal Display
Hard Disk Drive: 0.81 G Byte Internal, for System Software
Floppy Drive: 3.5",1.44 M Byte

Power & Storage Unit (PSU)

Power Supply: Converts 12 or 24v aircraft power for system use
Power Requirement: 350 Watts
Image Hard Disk Drive: 4 G Byte (Removable) Optional 9 G Byte
Expansion Slots: For additional 4 or 9 G Byte Image Storage hard disk drives
Image Transfer Tape Drive: 8 mm Exabyte, Optional 4 mm DAT

Real-time Image Targeting System

The color targeting system permits the system operator to view the same ground area as the digital sensors in real time.

Environmental
Temperature: 0 C to 40 C (32 F to 104 F)
Humidity: 5% to 95% relative humidity, non-condensing

Physical
Weight: 80 kg (175 lbs)
Dimensions:
Sensors - 60 x 60 x 45 cm (24" x 24" x 18")
Operator Console - 36 x 30 x 10 cm (14" x 12" x 4")
PSU - 56 x 56 x 17 cm (22" x 22" x 17")

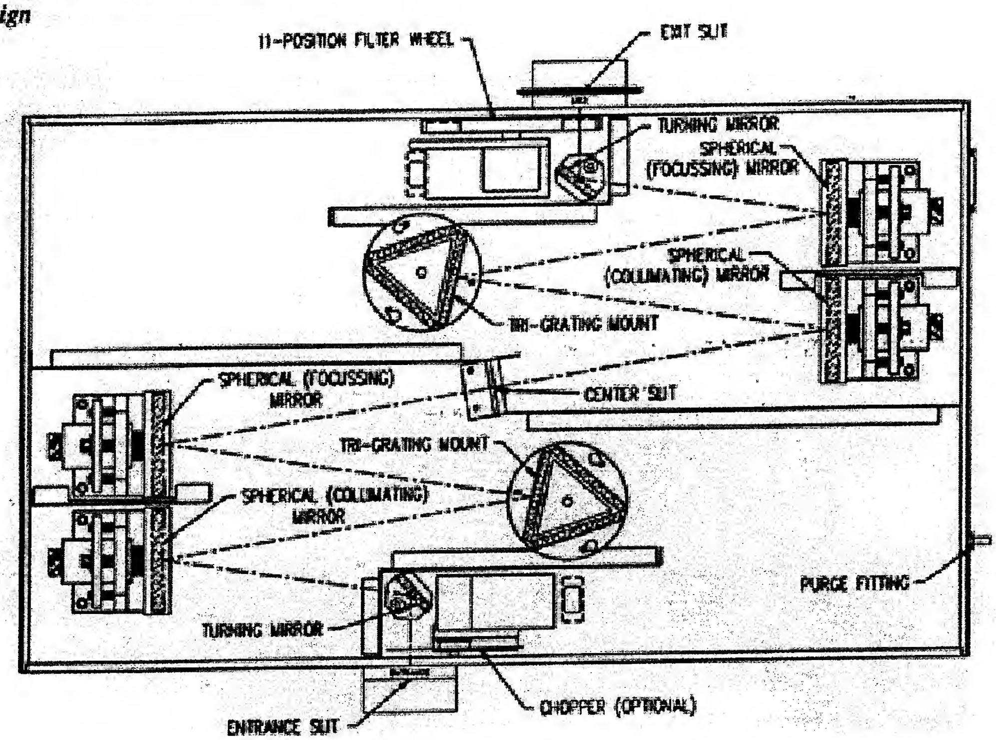
Aircraft
Type: Fixed wing or rotary
Speed Range: 10 to 400 knots
Camera Port: 40 - 45 cm (16" - 18") diameter minimum
Power: 350 Watts at 12 or 24 Volts DC

Appendix B. Equipment List

Manufacturer	Description	Model Number	Serial Number
Optronics	Spectroradiometer	OL 750	
"	IR/Visible Dual Source Attachment	740-20D/IR	95300258
"	Programmable DC Current Source	65A	98109150
"	Dual Monochromator (additive)	OL 750-D	98410066
"	Grating: 1200/mm, dispersion 2 nm/mm		
"	Grating: 600/mm, dispersion 4 nm/mm		
"	Quartz Lens Transmission Attachment	740-73	95100009
"	Detector Support Module	DSM-1A	98100075
"	Silicon Detector Head	DH-30	98101087
"	Spectroradiometer Controller	OL 750-C	98119143
DEC	90 MHz Pentium PC (Master Controller, IEEE-488)		
	Custom Filter Holder, for 60mm dia. filters. Shims: 5.32 mm for 5 deg tilt, and 10.60 for 10 deg tilt.		
Optronics	Automated Light Source, & Calibration Source Controller	OL 462	99406048
"	Calibration Source Optic Head	462-12-2	99102008
ACTON	Monochromator	500I	500104
Analytical Spectral Devices (ASD)	Spectroradiometer	FS FR	6116

Appendix C. Optronics OL 750

OL 750-M-D Double Monochromator Optical Design



OL 750-M-D Double Monochromator (Additive)

Six sets of fixed slits (0.125, 0.25, 0.5, 1.25, 2.5, and 5.0 mm) are provided with the OL 750-M-D Monochromator which enable the user to vary the half bandwidth (HBW). Various combinations of the entrance, center and exit slits can be used. The OL 750-635 Automated Entrance Slits and OL 750-636 Automated Exit Slits are optional items, which can be used to automatically change slits when turrets/gratings are changed. This permits the spectroradiometric system to operate in either constant bandwidth mode or constant slitwidth mode, depending on the measurement type. Table 3 lists the nominal HBW associated with some of the more commonly used combinations.

Table 3

HBW	Slit (mm)		
(nm)	Entrance	Middle	Exit
0.25	0.125	1.25	0.125
0.5	0.25	2.5	0.25
1	0.5	5.0	0.5
2.5	1.25	5.0	1.25
5	2.5	5.0	2.5
10	5.0	5.0	5.0

The BW is calculated by multiplying the dispersion factor (nm/mm) by the exit slit width (mm).

> Note:
>
> In the OL 750-M-D Double Monochromator, a removable access plate is provided in the monochromator top cover in order to gain access to the middle slit.
>
> For smaller slit sizes, a larger middle slit is recommended for increased signal throughput and stability without affecting the HBW. Using a middle slit at least three sizes larger than the width of the entrance/exit slits is sufficient for optimum performance.

OL 750-M-D Double Monochromator (Additive) – Technical Specifications

Wavelength Range	0.20 µm to 30 µm
Wavelength Accuracy	±0.05%
Wavelength Precision	±0.01%
Wavelength Mechanical Drive	Direct geared
Dispersion[1/]	2 nm/mm
Bandwidth[1/] [2/]	0.25 nm to 10 nm
Stray Light	10^{-8}
Grating Size	68mm x 68 mm
Focal Length	254 mm (f/4)
Filter Positions	11
Chopper Rate [3/]	Programmable 10-350 Hz
Size	16 ½ x 28 x 9 ½ inches (42 x 63 x 24 cm)
Weight	62 lbs. (82 kg)
Operating Temperature	5°C to 40°C

1/ 1200 g/mm gratings

2/ Narrower Bandwidth obtainable with optional smaller size slits. The OL 750-635 and OL 750-636 Automated Entrance and Exit Slits are optional items, which can be used to automate the slits when gratings or turrets are changed.

3/ An optional extended frequency range optical chopper is available.

OL 750-C Controller, SNR 98119143
OL 750-M-S-NVG Monochromator, SNR 98410066
September 24, 1998

Options

750-423 Source Measurement	Installed
750-424 Transmittance	Not Installed
750-425 Detector Response	Installed
750-427 Diffuse Reflectance	Not Installed
750-428 Quantum Efficiency	Not Installed
750-429 Specular Reflectance	Not Installed
750-430 Quick Scan	Not Installed
750 Extended Chopper Range	Not Installed
750-422 Radiometer/Photometer	Not Installed
750-SDS-250 CCD Detector	Not Installed
750-423-NVG Data Reduction	Not Installed
750 PMT High Voltage	200.0 → 1100.0 Volts

GRATING DEFAULTS

Turret 1 Grating 1

Lower Effective Wavelength	:	250.00 nm
Upper Effective Wavelength	:	1100.00 nm
Cut-On Wavelength	:	250.00 nm
Grooves per mm	:	1200
Blaze Wavelength	:	500.00 nm
Grating Alignment Factor	:	1.0000
Grating Alignment Angle	:	0.010

Turret 1 Grating 2

Lower Effective Wavelength	:	500.00 nm
Upper Effective Wavelength	:	1800.00 nm
Cut-On Wavelength	:	662.00 nm
Grooves per mm	:	600
Blaze Wavelength	:	1000.00 nm
Grating Alignment Factor	:	1.0002
Grating Alignment Angle	:	120.006

Turret 1 Grating 3

Lower Effective Wavelength	:	1200.00 nm
Upper Effective Wavelength	:	3500.00 nm
Cut-On Wavelength	:	1325.00 nm
Grooves per mm	:	300
Blaze Wavelength	:	2000.00 nm
Grating Alignment Factor	:	1.0000
Grating Alignment Angle	:	240.003

Turret 2 Grating 1

Lower Effective Wavelength	:	1900.00 nm
Upper Effective Wavelength	:	6500.00 nm
Cut-On Wavelength	:	2825.00 nm
Grooves per mm	:	150
Blaze Wavelength	:	4000.00 nm
Grating Alignment Factor	:	1.0000
Grating Alignment Angle	:	0.006

Turret 2 Grating 2

Lower Effective Wavelength	:	5500.00 nm
Upper Effective Wavelength	:	14500.00 nm
Cut-On Wavelength	:	6200.00 nm
Grooves per mm	:	75
Blaze Wavelength	:	10000.00 nm
Grating Alignment Factor	:	1.0002
Grating Alignment Angle	:	119.997

FILTER WHEEL DEFAULTS

Filter 1 Cut-On Wavelength	:	290.00 nm
Filter 2 Cut-On Wavelength	:	345.00 nm
Filter 3 Cut-On Wavelength	:	602.00 nm
Filter 4 Cut-On Wavelength	:	1119.00 nm
Filter 5 Cut-On Wavelength	:	1949.00 nm
Filter 6 Cut-On Wavelength	:	3599.00 nm
Filter 7 Cut-On Wavelength	:	6399.00 nm
Filter 8 Cut-On Wavelength	:	10999.00 nm
Filter 9 Cut-On Wavelength	:	DISABLES
Filter 10 Cut-On Wavelength	:	Shut

SYSTEM PRINTER DEFAULTS

Epson/IBM compatible high quality on LPT1.
Print during scans : No

SIGNAL ACQUISITION TIME DEFAULTS

Fast Settling Time	:	0.50 seconds
Fast Integration Time		:0.50 seconds
Medium Settling Time	:	1.00 seconds
Medium Integration Time	:	1.50 seconds
Slow Settling Time	:	2.00 seconds
Slow Integration Time	:	4.00 seconds
Super High Sensitivity Settling Time	:7.00 seconds	
Super High Sensitivity Integration Time	:7.00 seconds	

OL 750 COMMUNICATION INTERFACE

The 750 is attached by GPIB (controller address 0, device address 3).

DETECTOR INPUT CONFIGURATION

Detector Channel A : OL 750-HSD-300 Silicon (AC)
Detector Channel B : OL 750-HSD-350 PbSe (AC)

DETECTOR DEFAULTS

OL 750-HSD-300 Silicon (AC) Defaults

Signal Detection System	:	AC Lock-In Amplification
Detector Support Module	:	DSM-1A
Signal Acquisition Time	:	Adaptive
Lower Effective Wavelength	200.00 nm	
Upper Effective Wavelength	1100.00 nm	
Cut-on Wavelength	:	200.00 nm
Chopper Frequency	167.00 Hz	
Noise Threshod	:	0.000E+000
User Settling Time	:	2.00 seconds
User Integration Time		2.00 seconds
Gain Correction	:	1.000E+000

Adaptive Mode Signal Acquisition Times:

Signal Level 1.000E-03	:	Fast	(Enabled)
Signal Level 1.000E-04	:	Fast	(Enabled)
Signal Level 1.000E-05	:	Fast	(Enabled)
Signal Level 1.000E-06	:	Fast	(Enabled)
Signal Level 1.000E-07	:	Fast	(Enabled)
Signal Level 1.000E-08	:	Fast	(Enabled)
Signal Level 1.000E-09	:	Medium	(Enabled)
Signal Level 1.000E-10	:	Medium	(Enabled)
Signal Level 1.000E-11	:	Slow	(Enabled)

OL 750-HSD-350 PbSe (AC) Defaults

Signal Detection System	:	AC Lock-In Amplification
Detector Support Module	:	DSM-2 (AC)
Signal Acquisition Time	:	Adaptive
Lower Effective Wavelength	1000.00 nm	
Upper Effective Wavelength	5000.00 nm	
Cut-on Wavelength	:	1000.00 nm
Chopper Frequency	167.00 Hz	
Noise Threshod	:	0.000E+000
User Settling Time	:	2.00 seconds
User Integration Time		2.00 seconds
Gain Correction	:	1.000E+000

Adaptive Mode Signal Acquisition Times:

Signal Level 1.000E+01	: Fast	(Enabled)
Signal Level 1.000E+00	: Fast	(Enabled)
Signal Level 1.000E-01	: Fast	(Enabled)
Signal Level 1.000E-02	: Fast	(Enabled)
Signal Level 1.000E-03	: Medium (Enabled)	
Signal Level 1.000E-04	: Slow	(Enabled)

DARK CURRENT ACQUISITION CONFIGURATION

Measure Dark Current At : Shutter
Number of Dark Readings to Average : 1

Appendix D. Filter Spectral Transmittance Measurement

Filter Spectral Transmittance Measurements
Transmittance of all four spectral band filters was measured at 0, 5 and 10 degrees off normal incidence.

Equipment: Primary equipment used was the Optronics Model OL 750 Spectroradiometer (and multiple subsystem components; see Appendix B: Equipment List). The configuration utilized the first and second gratings with dispersions of 2 and 4 nm/mm respectively. Input and output slits of 2.5 mm provided a FWHM of 5 and 10 nm at each wavelength setting. The source used was the QTH lamp. All measurements were taken at 5 nm intervals. The range chosen for scans was based on manufacturer-supplied data.

Setup. Figure 19 shows the inter-relationship between the components and the optical path within the spectroradiometer used for the filter transmittance measurements.

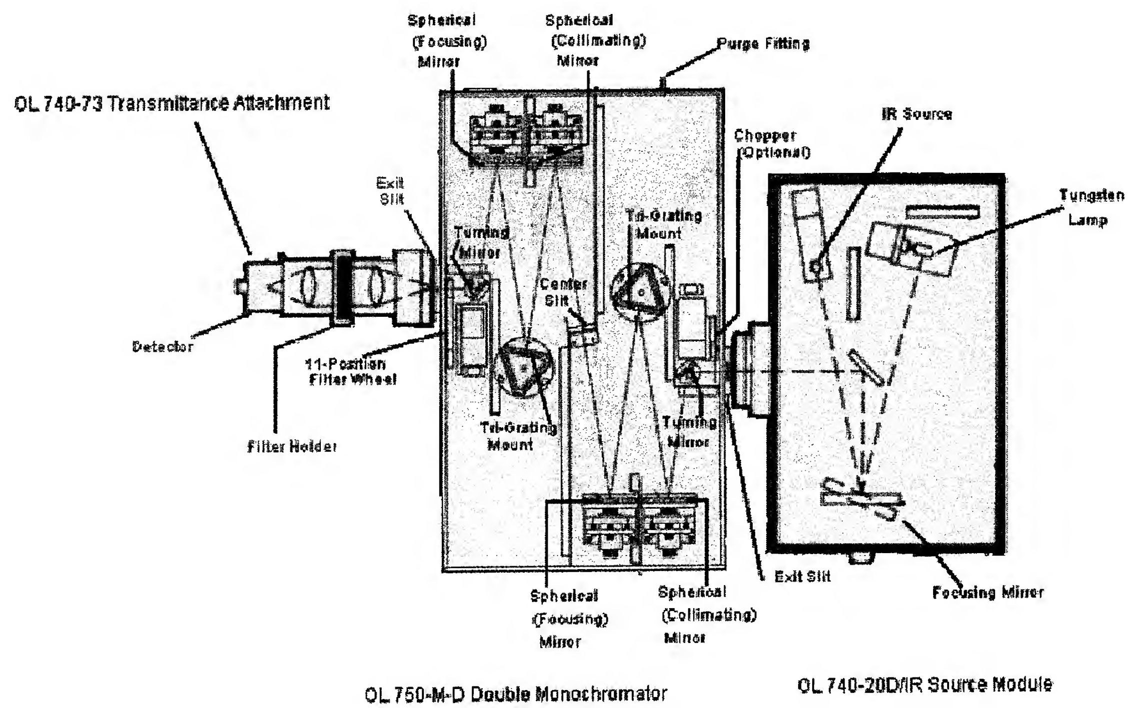


Figure 19. Spectral transmittance measurement setup.

Figure 20 shows the actual arrangement on the optical table in the laboratory. The general arrangement corresponds to the diagram in Figure 19.

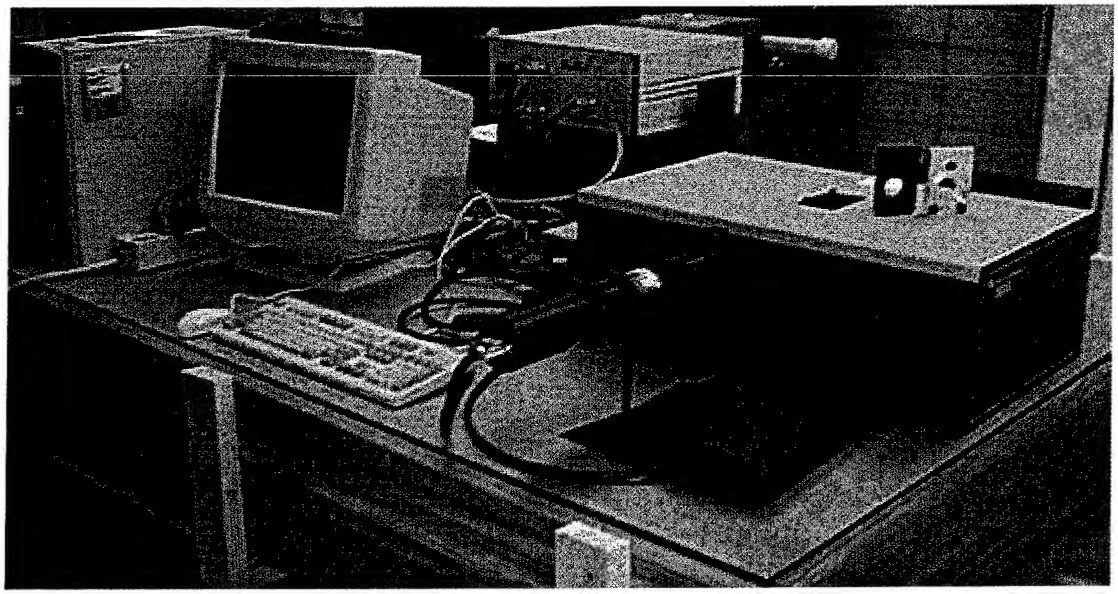


Figure 20. Monochromator, filter holders, etc.

The filter holders are shown on top of the monochromator. The bare aluminum holder on the right was specially machined to accept the 60 mm diameter filters. Off-normal measurements of 5 and 10 degrees were implemented by using shims under one edge of the filter. Pictured are the programmable current source lamp driver, the master controller and the computer used for overall system control and data processing.

Procedure. Initial measurements were taken on each filter in sequence. A quick-look plotting utility was utilized to insure that the data just taken was acceptable. Out of band transmittance for all filters was at least 10^{-4} or lower. Table 12 shows the spectral ranges scanned for each of the filters. All entries are in nanometers (nm). In all cases the sampling interval was 5 nm.

Table 12. Filter scan range.

FILTER	SCAN RANGE	FWHM SPEC
BLUE	350-600	450-515
GREEN	450-650	525-605
RED	600-750	630-690
Near-IR	670-950	750-900

- The spectroradiometer was powered up and given time to stabilize.
- The instrument was programmed for the desired spectral range and step size.
- A "calibration" (.cal) file was generated by measuring signal level with 100% transmittance (no filter installed). This .cal file was used as reference for the three scans with the filter in place.
- The filter to be measured was mounted in the filter holder.
- Scan 1: normal incidence transmittance

- Scan 2: 5 degree off-normal (shim installed)
- Scan 3: 10 degree off-normal (shim installed)
- The instrument divides the signal level measured with the filter in place by the signal level measured with no filter, as recorded in the .cal file, to derive transmittance

Results / Analysis

Graphs (spectral transmittance curves) were generated for the absolute transmittance data at each of the incidence angle data sets are shown in Figures 21-24 and Tables 13-16. Each spectral transmittance curve was normalized. To obtain 50% values, short- and long-wavelength edges were obtained by linear extrapolation between closest samples. Edge slopes were evaluated at sample points closest to 50%. All slope values exceeded the specified minimum of greater than 20%/20nm at half-max except for the blue short wavelength edge.

Blue Band Filter

	Short Cutoff	Long Cutoff	FWHM
Normal	416	517	101
5 degrees	416	516	100
10 degrees	415	514	99
Spec	450±10	515±10	65

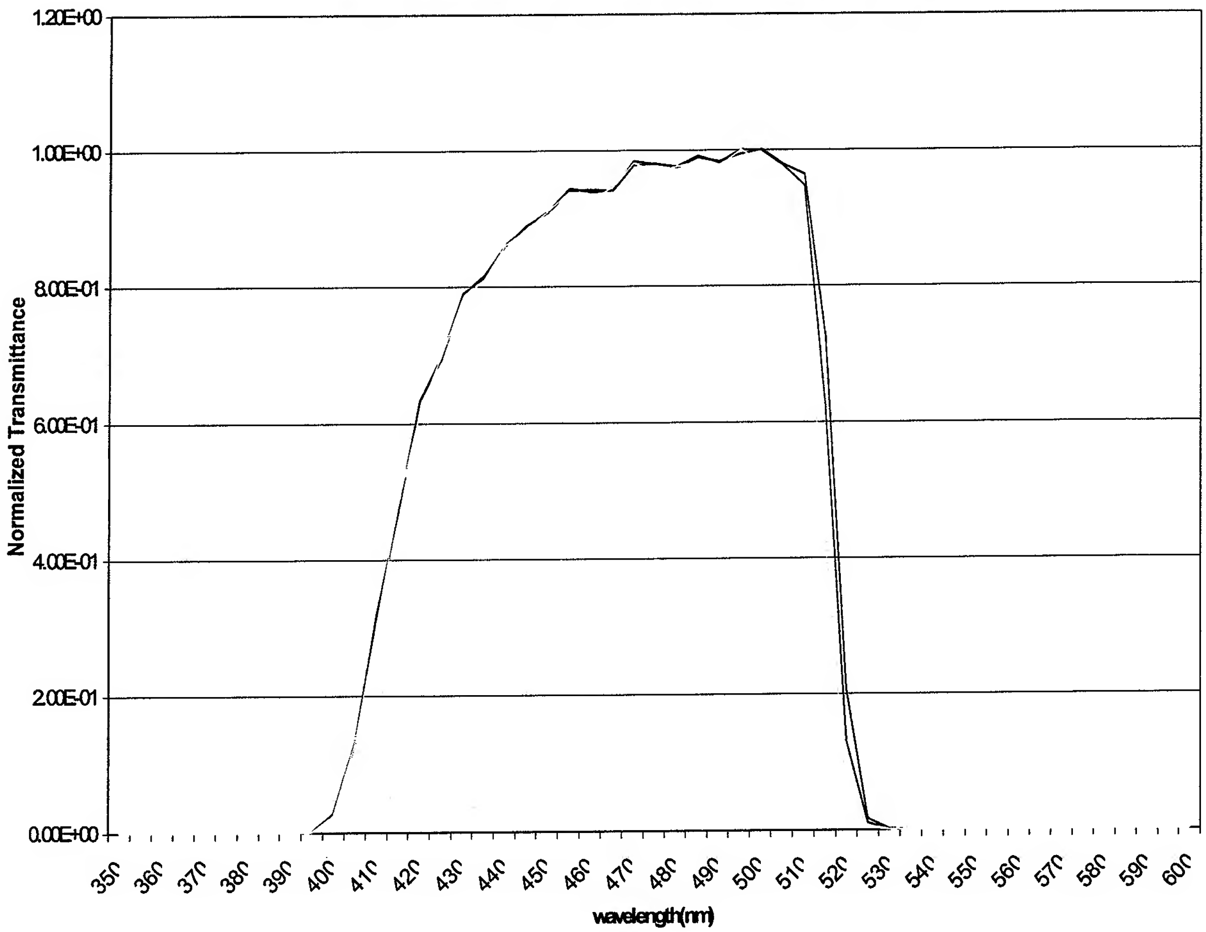


Figure 21. Blue filter transmittance.

	Short Edge	Long Edge
Specified	1%/1nm	1%/1nm
Measured	3.1%/1nm	7.1%/1nm

Table 13. Blue filter edge slopes.

Green Band Filter

	Short Cutoff	Long Cutoff	FWHM
Normal	515	599	84
5 degrees	515	597	82
10 degrees	515	595	80
Spec	525	605	80

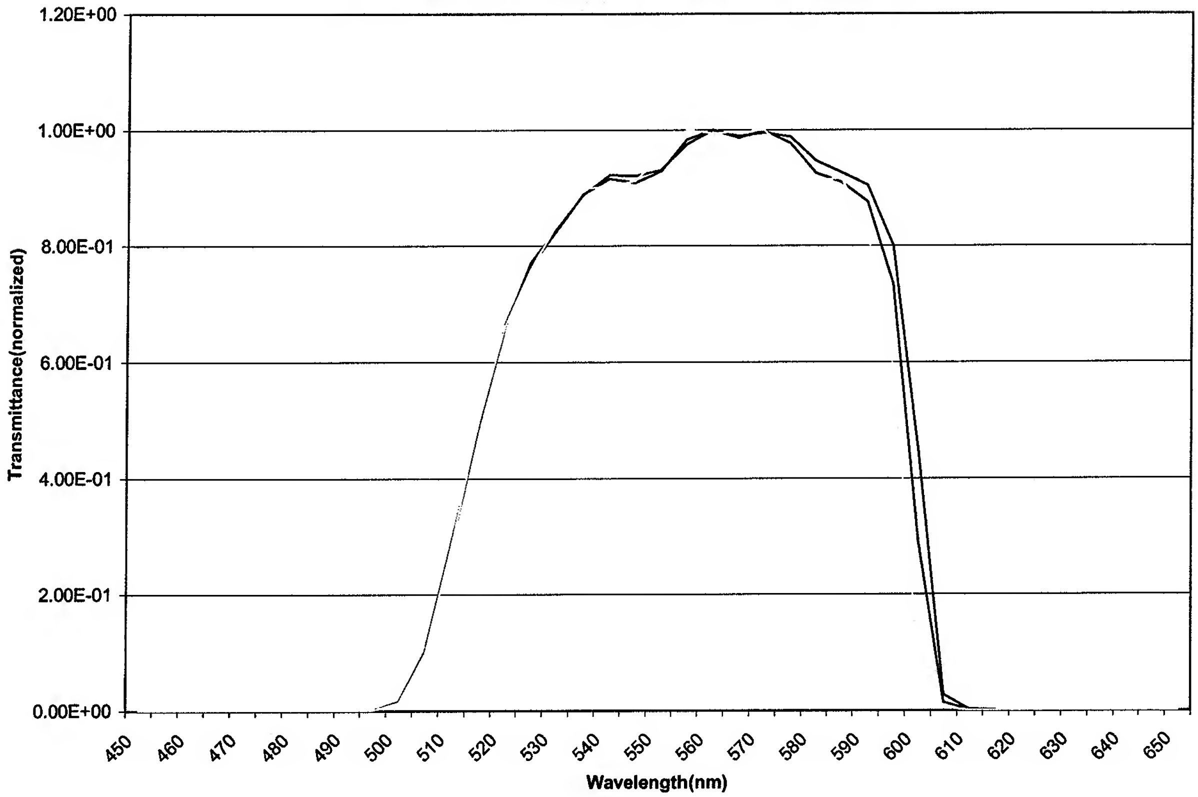


Figure 22. Green filter transmittance.

	Short Edge	Long Edge
Specified	1%/1nm	1%/1nm
Measured	3.7%/1nm	7.7%/1nm

Table 14. Green filter edge slopes.

Red Filter

	Short Cutoff	Long Cutoff	FWHM
Normal	639	698	59
5 degrees	638	697	59
10 degrees	637	694	57
Spec	630	690	60

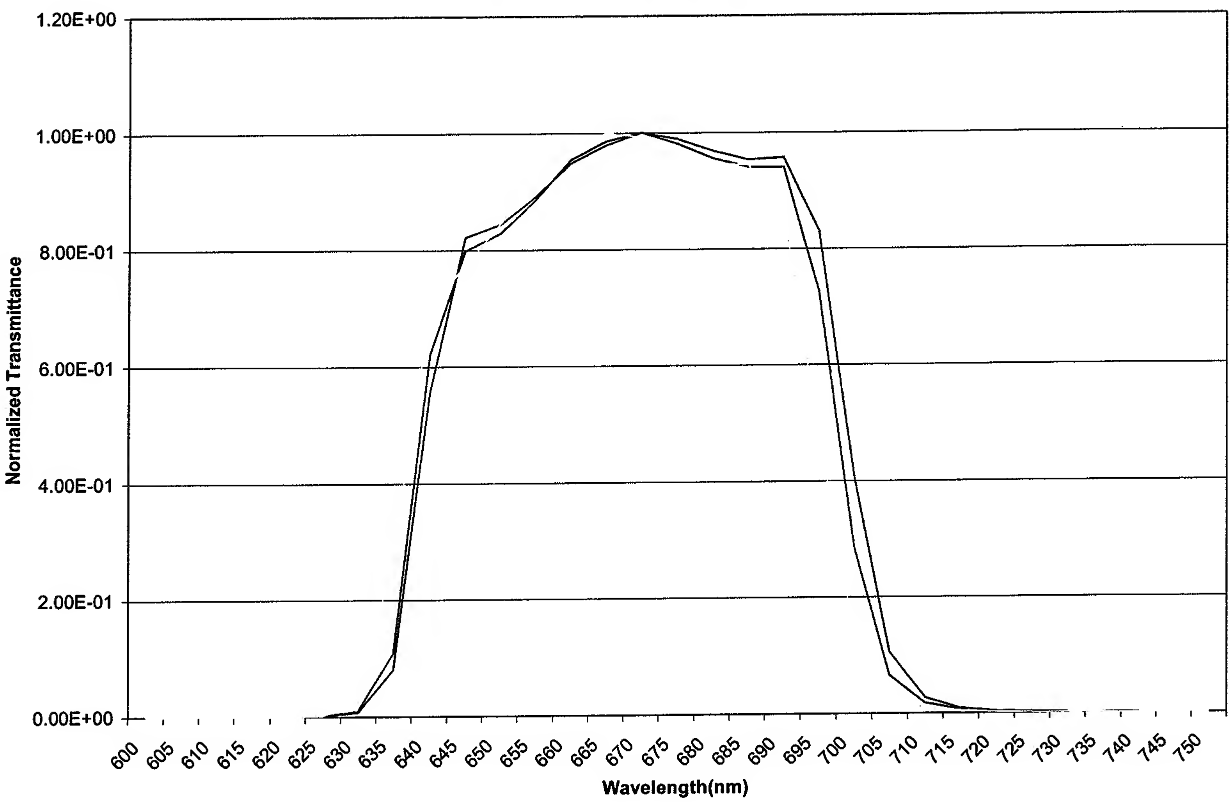


Figure 23. Red filter transmittance.

	Short Edge	Long Edge
Specified	1%/1nm	1%/1nm
Measured	7.4%/1nm	7.3%/1nm

Table 15. Red filter edge slopes.

Near-IR Filter

	Short Cutoff	Long Cutoff	FWHM
Normal	740	900	160
5 degrees	740	898	158
10 degrees	741	895	154
Spec	750	900	150

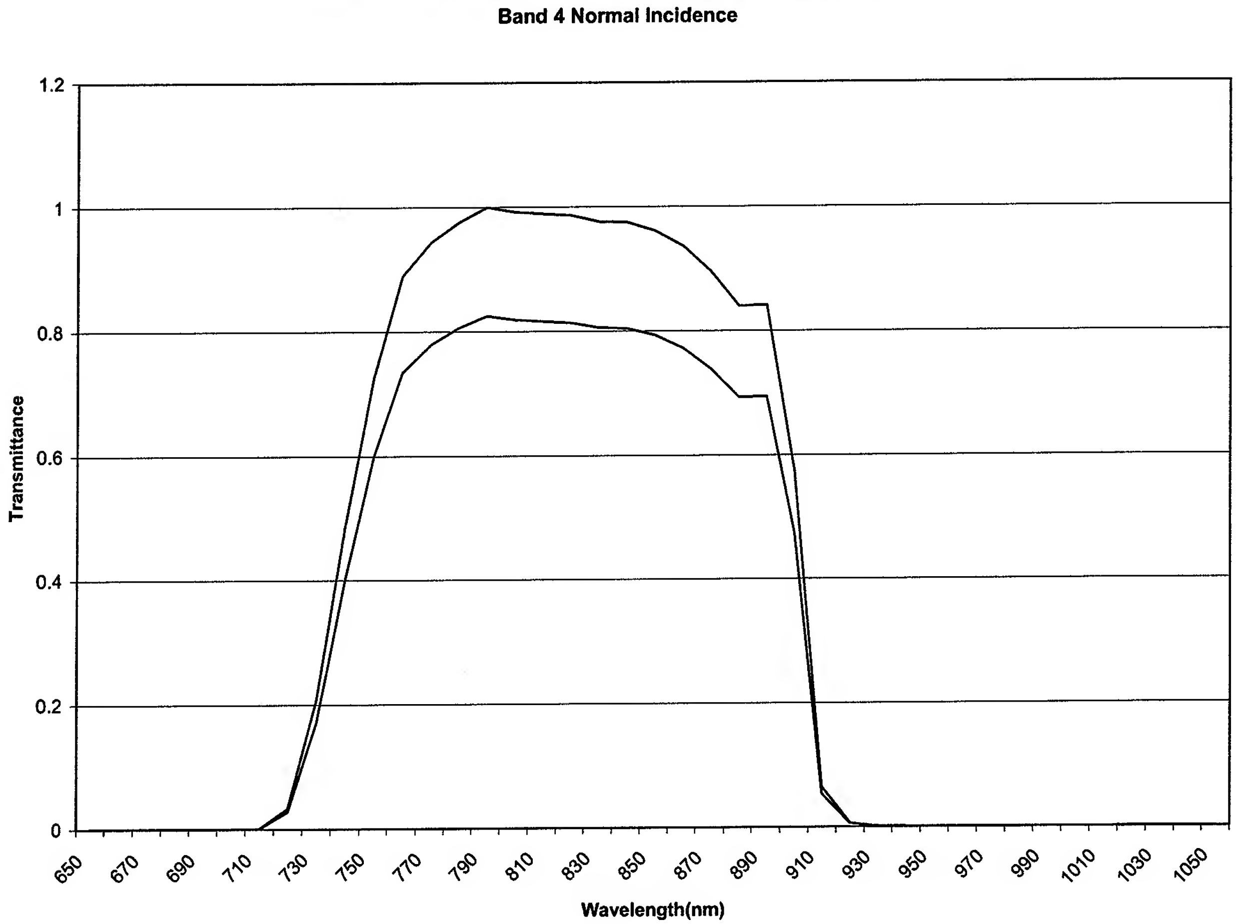


Figure 24. Near-IR filter transmittance

Units: %/nm	Short Edge	Long Edge
Measured-Normal	2.4	5.0
Measured-5 degrees	2.5	4.3
Measured-10 degrees	2.6	5.9
Specified	>1	>1

Table 16. Near-IR filter edge slopes.

To estimate spectral response of each band of the sensor, filter spectral transmittance measured during the tests was multiplied by the typical spectral quantum efficiency of the CCD array supplied by KODAK for the model KAF-1602. See Figure 25.

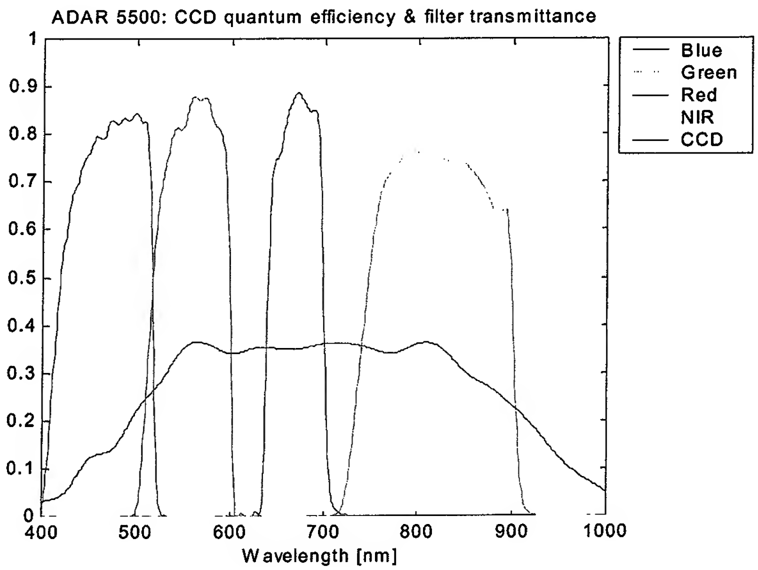


Figure 25. Kodak KAF-1602 CCD quantum efficiency & filter transmittance.

Table 17 shows the (approximate) system spectral cutoffs as calculated from filter measurements and CCD manufacturer quantum efficiency curves. The manufacturer's CCD quantum efficiency curves are shown in Appendix E.

Table 17. FWHM using filter spectral measurements times CCD quantum efficiency.

Blue Band	**Short Cutoff**	**Long Cutoff**	**FWHM**
Normal (0 deg.)	455	517	62
5 deg. Off Axis	455	516	61
10 deg. Off Axis	454	514	60
Spec	450	515	65
Green Band			
Normal (0 deg.)	520	599	79
5 deg. Off Axis	520	599	79
10 deg. Off Axis	520	596	76
Spec	525	605	80
Red Band			
Normal (0 deg.)	640	699	59
5 deg. Off Axis	639	698	58
10 deg. Off Axis	638	695	57
Spec	630	690	60
NIR Band			
Normal (0 deg.)	741	901	160
5 deg. Off Axis	742	898	156
10 deg. Off Axis	742	894	152
Spec	750	900	150

Omega Optics Filter Spectral Transmission and Density Curves

The following curves are provided by Omega Optics.

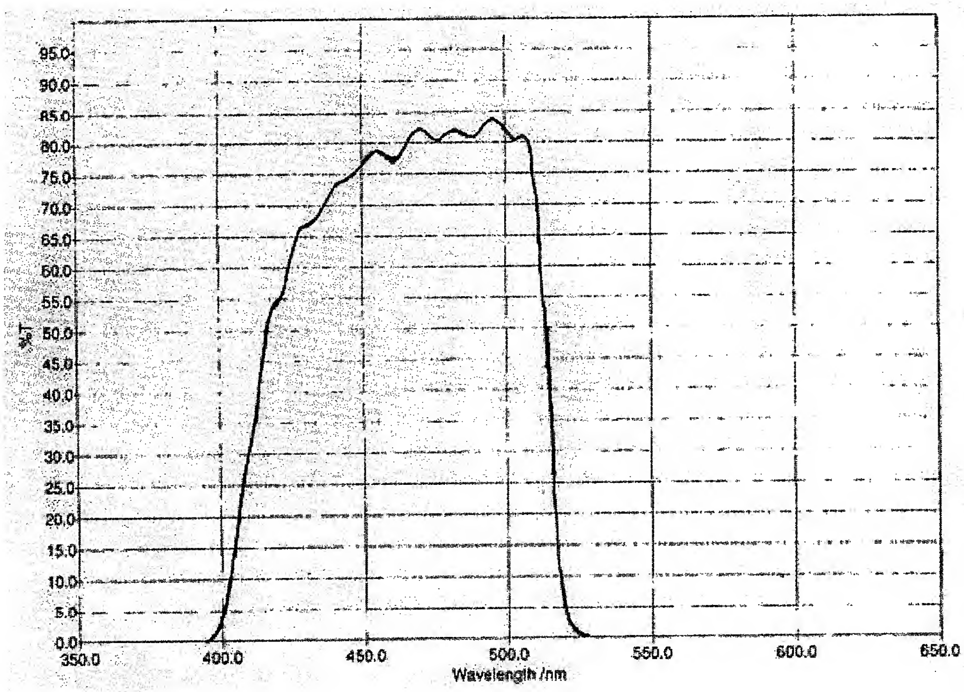


Figure 26. Blue filter spectral transmission (from manufacturer).

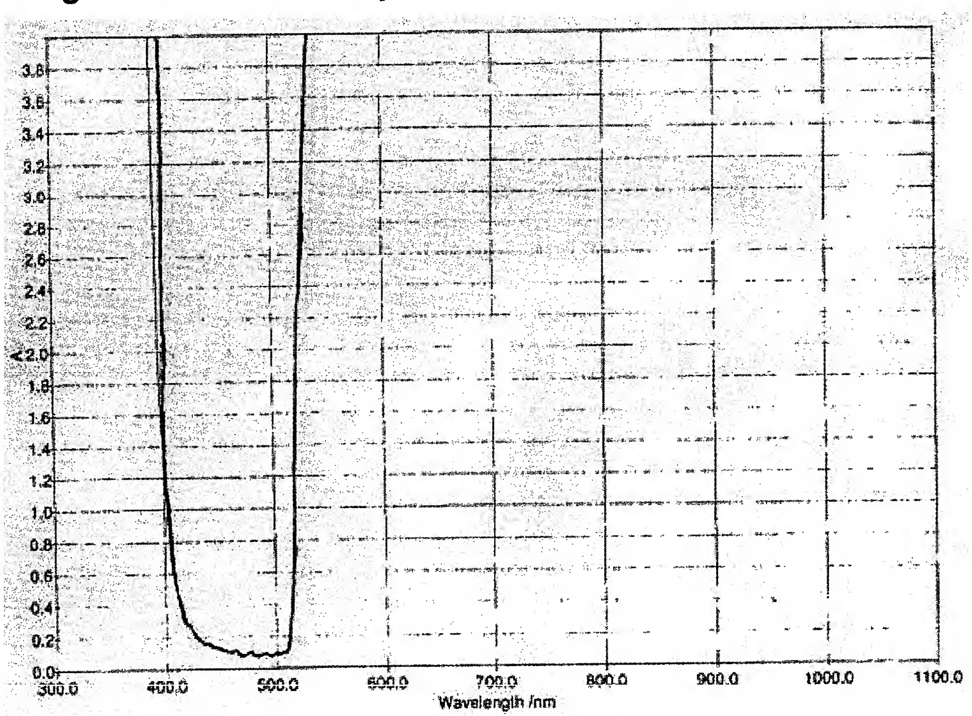


Figure 27. Blue filter optical density (from manufacturer).

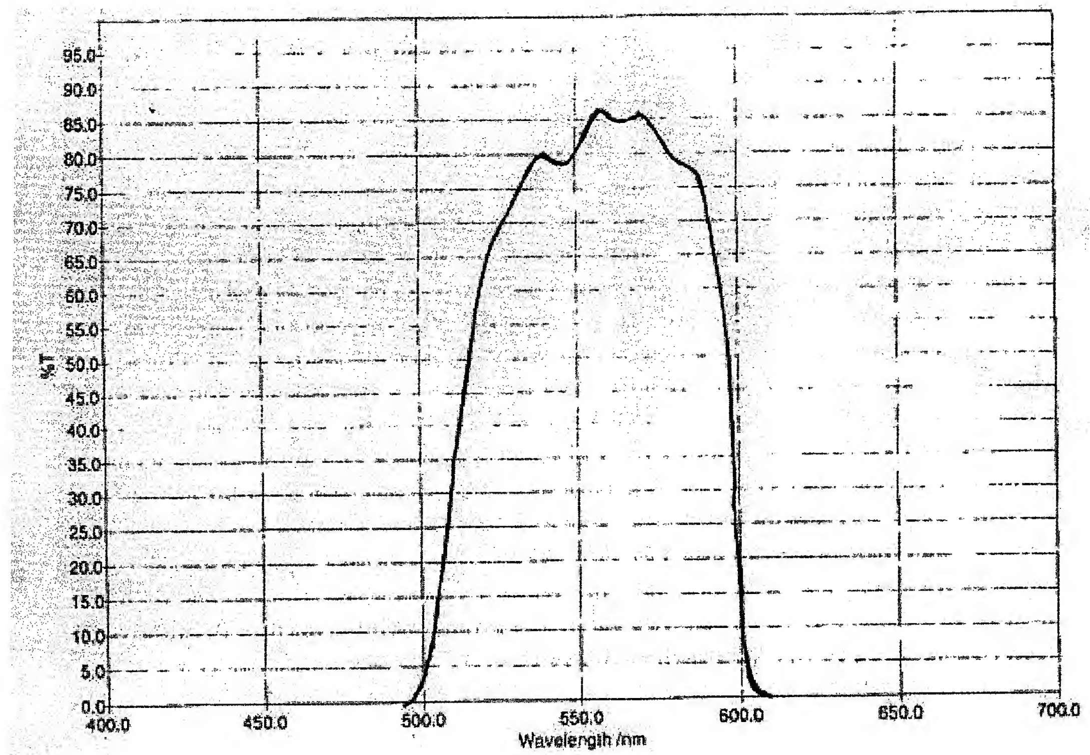


Figure 28. Green filter spectral transmission (from manufacturer).

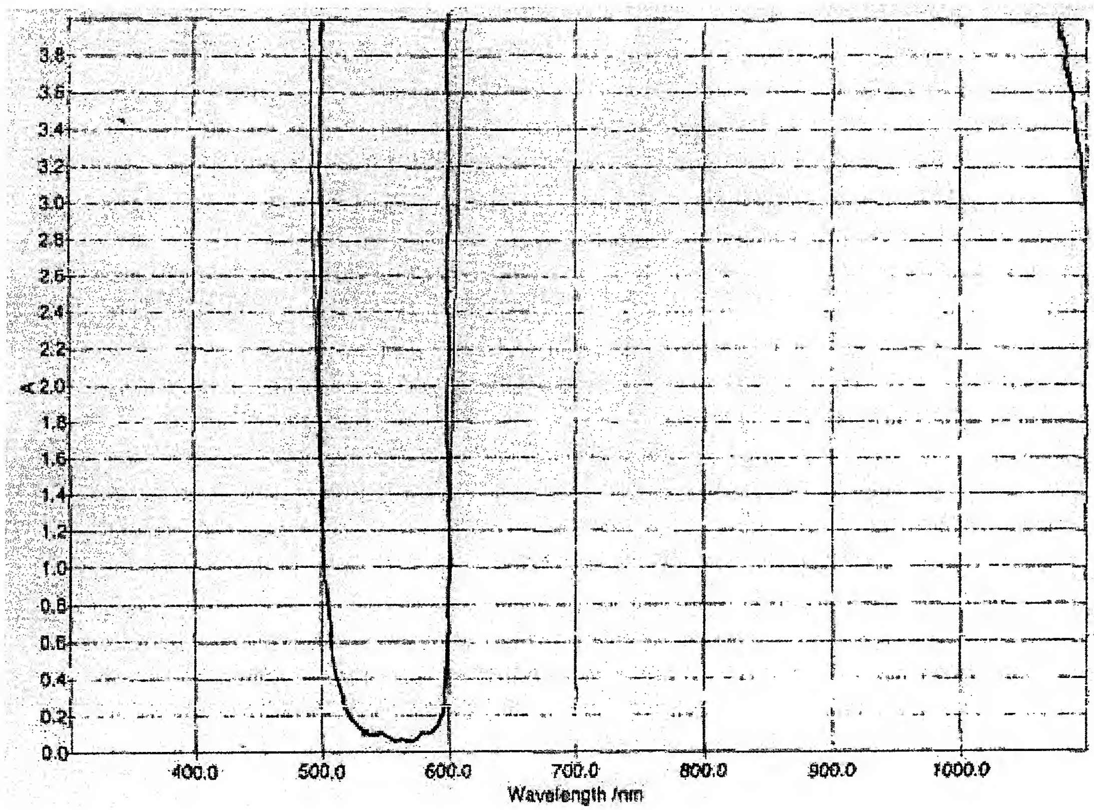


Figure 29. Green filter optical density (from manufacturer).

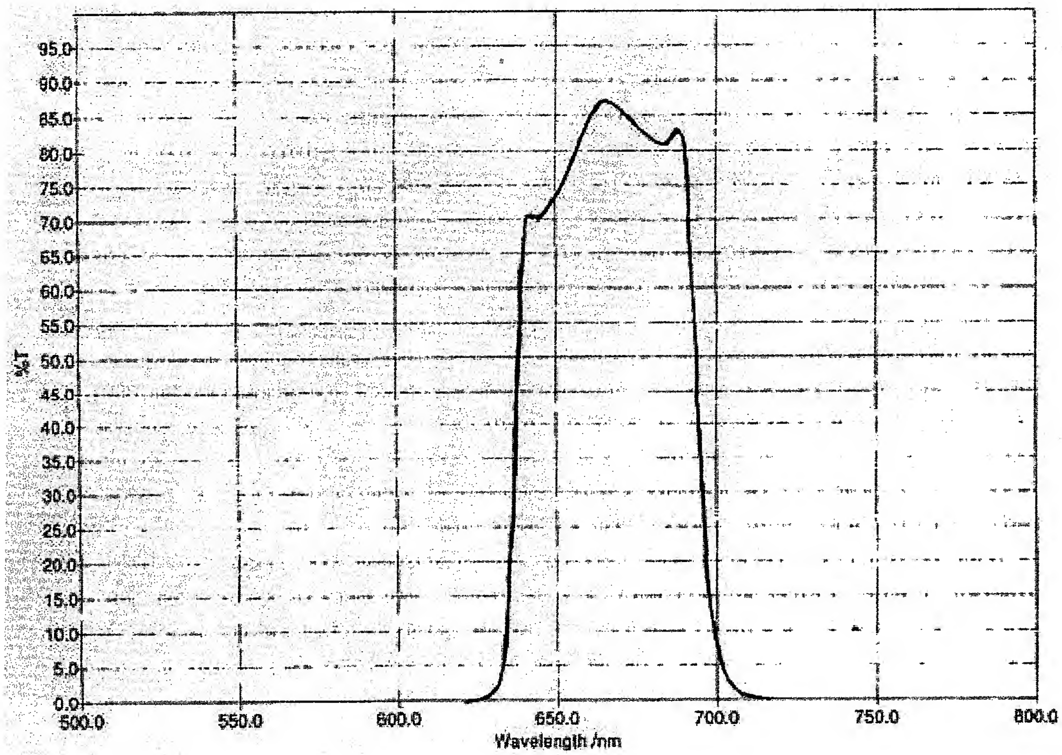


Figure 30. Red filter spectral transmission (from manufacturer).

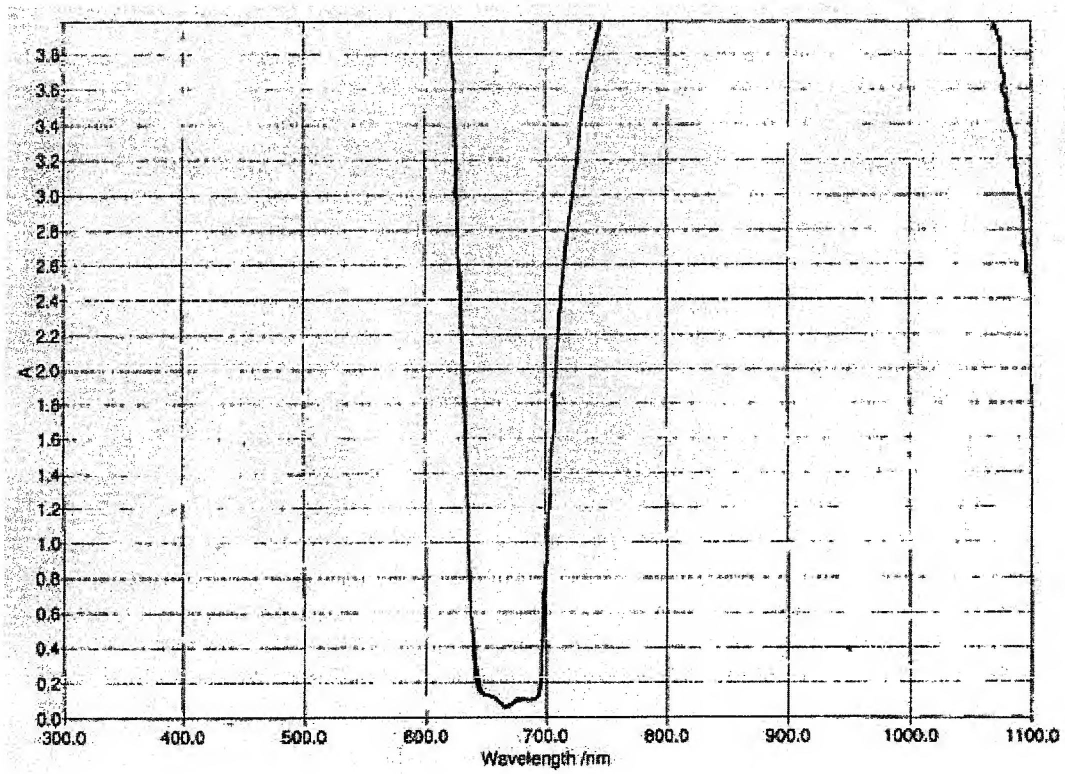


Figure 31. Red filter optical density (from manufacturer).

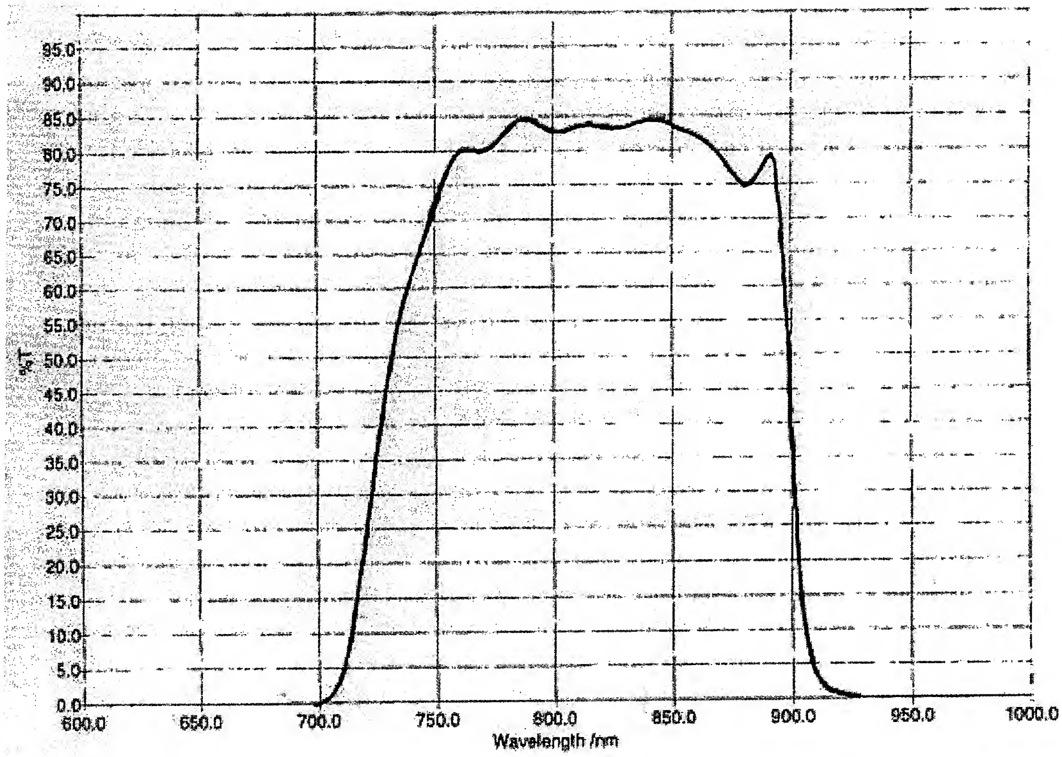


Figure 32. NIR filter spectral transmission (from manufacturer).

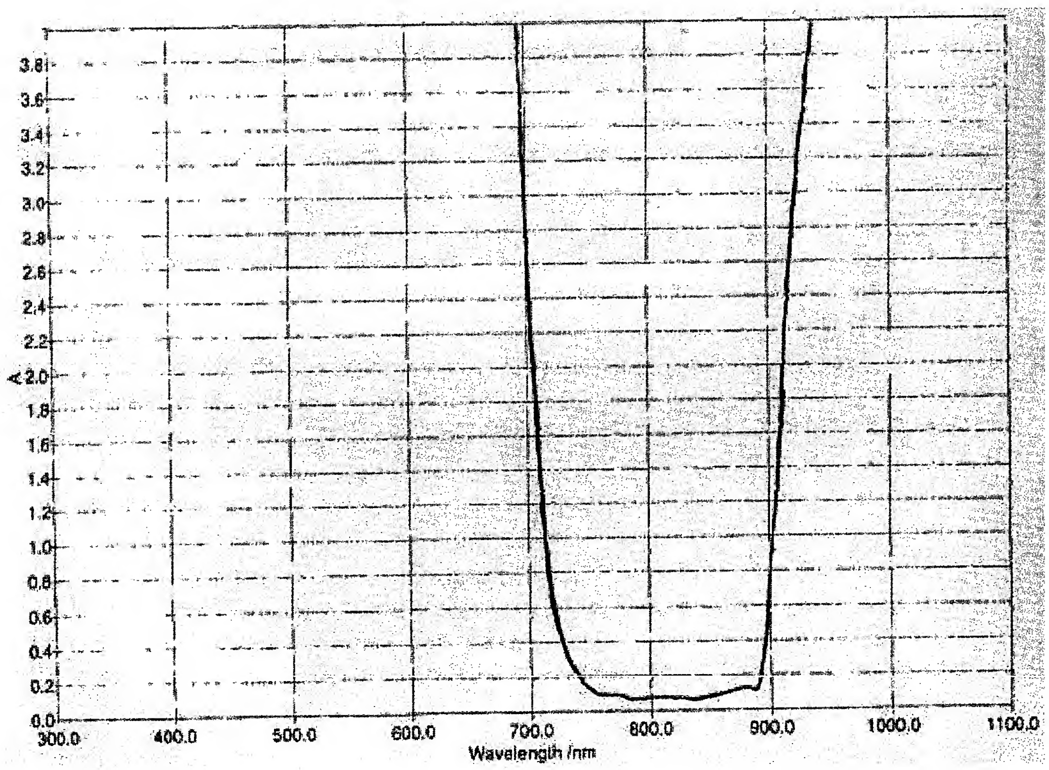


Figure 33. NIR optical density (from manufacturer)

Appendix E. KODAK KAF: 1600 Series Image Sensor Megapixel Full-Frame CCD Info

KAF - 1600

1536 (H) x 1024 (V) Pixel

Full-Frame CCD Image Sensor

Performance Specification

Eastman Kodak Company

Microelectronics Technology Division

Rochester, New York 14650-2010

Revision 3

August 12, 1998

TABLE OF CONTENTS

APPENDIX

FIGURES

1.1 Features

1.6M Pixel Area CCD
1536H x 1024V (9 mm) Pixels
13.8 mm H x 9.2 mm V Photosensitive Area
2-Phase Register Clocking
Enhanced Responsivity
100% Fill Factor
High Output Sensitivity (10mV/e-)
Low Dark Current (<10pA/cm 2 @ 25 o C)

1.2 Description

The KAF-1600 is a high performance monochrome area CCD (charge-coupled device) image sensor with 1536H x 1024V photoactive pixels designed for a wide range of image sensing applications in the 0.4 nm to 1.0 nm wavelength band. Typical applications include military, scientific, and industrial imaging. A 74 dB dynamic range is possible when operating at room temperature.

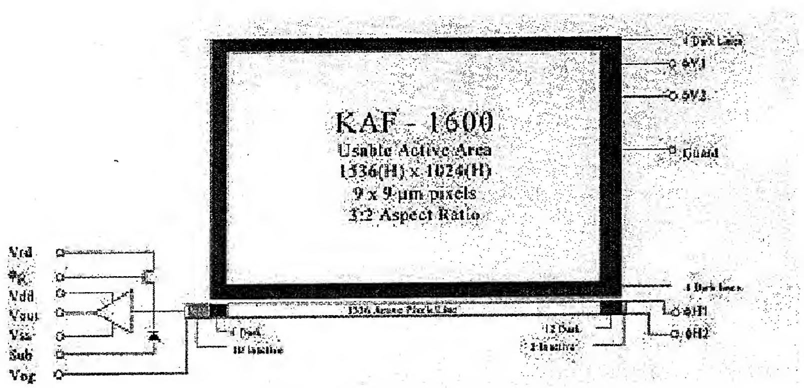


Figure 1. Functional Block Diagram.

The sensor is built with a true two-phase CCD technology. This technology simplifies the support circuits that drive the sensor and reduces the dark current without compromising charge capacity. Total chip size is 13.8mm x 9.2mm and is housed in a 24-pin, 0.805" wide DIL ceramic package with 0.1" pin spacing.

The sensor consists of 1552 parallel (vertical) CCD shift registers each 1032 elements long. These registers act as both the photosensitive elements and as the transport circuits that allow the image to be sequentially read out of the sensor. The elements of these registers are arranged into a 1536 x 1024 photosensitive array surrounded by a light shielded dark reference of 16 columns and 8 rows. Parallel (vertical) CCD registers transfer the image one line at a time into a single 1564 element (horizontal) CCD shift register. The horizontal register transfers the charge to a single output amplifier. The output amplifier is a two-stage source follower that converts the photo generated charge to a voltage for each pixel.

1.3 Image Acquisition

An electronic representation of an image is formed when incident photons falling on the sensor plane create electron-hole pairs within the sensor. These photon induced electrons are collected locally by the formation of potential wells at each photogate or pixel site. The number of electrons collected is linearly dependent on light level and exposure time and non-linearly dependent on wavelength. When the pixel's capacity is reached, excess electrons will leak into the adjacent pixels within the same column. This is termed blooming. During the integration period, the ϕV1and ϕV2 register clocks are held at a constant (low) level. See Figure 5 - Timing Diagrams.

1.4 Charge Transport

Referring again to Fig. 5 - Timing Diagrams, the integrated charge from each photogate is transported to the output using a two step process. Each line (row) of charge is first transported from the vertical CCD's to the horizontal CCD register using the ϕV1and ϕV2 register clocks. The horizontal CCD is presented a new line on the falling edge of ϕV2 while ϕH1 is held high. The horizontal CCD's then transport each line, pixel by pixel, to the output structure by alternately clocking the ϕH1 and ϕH2 pins in a complementary fashion. On each falling edge of ϕH1 a new charge packet is transferred onto a floating diffusion and sensed by the output amplifier.

1.5 Output Structure

Charge presented to the floating diffusion (FD) is converted into a voltage and current amplified in order to drive off-chip loads. The resulting voltage change seen at the output is linearly related to the amount of charge placed on FD. Once the signal has been sampled by the system electronics, the reset gate (ϕ_R) is clocked to remove the signal and FD is reset to the potential applied by VRD. More signal at the floating diffusion reduces the voltage seen at the output pin. In order to activate the output structure, an off-chip load must be added to the Vout pin of the device - see Figure 4.

1.6 Dark Reference Pixels

Surrounding the peripheral of the device is a border of light shielded pixels. This includes 4 leading and 12 trailing pixels on every line excluding dummy pixels. There are also 4 full dark lines at the start of every frame and 4 full dark lines at the end of each frame. Under normal circumstances, these pixels do not respond to light. However, dark reference pixels in close proximity to an active pixel, or the outer bounds of the chip (including the first two lines out), can scavenge signal depending on light intensity and wavelength and therefore will not represent the true dark signal.

1.7 Dummy Pixels

Within the horizontal shift register are 10 leading and 2 trailing additional shift phases which are not associated with a column of pixels within the vertical register. These pixels contain only horizontal shift register dark current signal and do not respond to light. A few leading dummy pixels may scavenge false signal depending on operating conditions.

2.1 Package Drawing

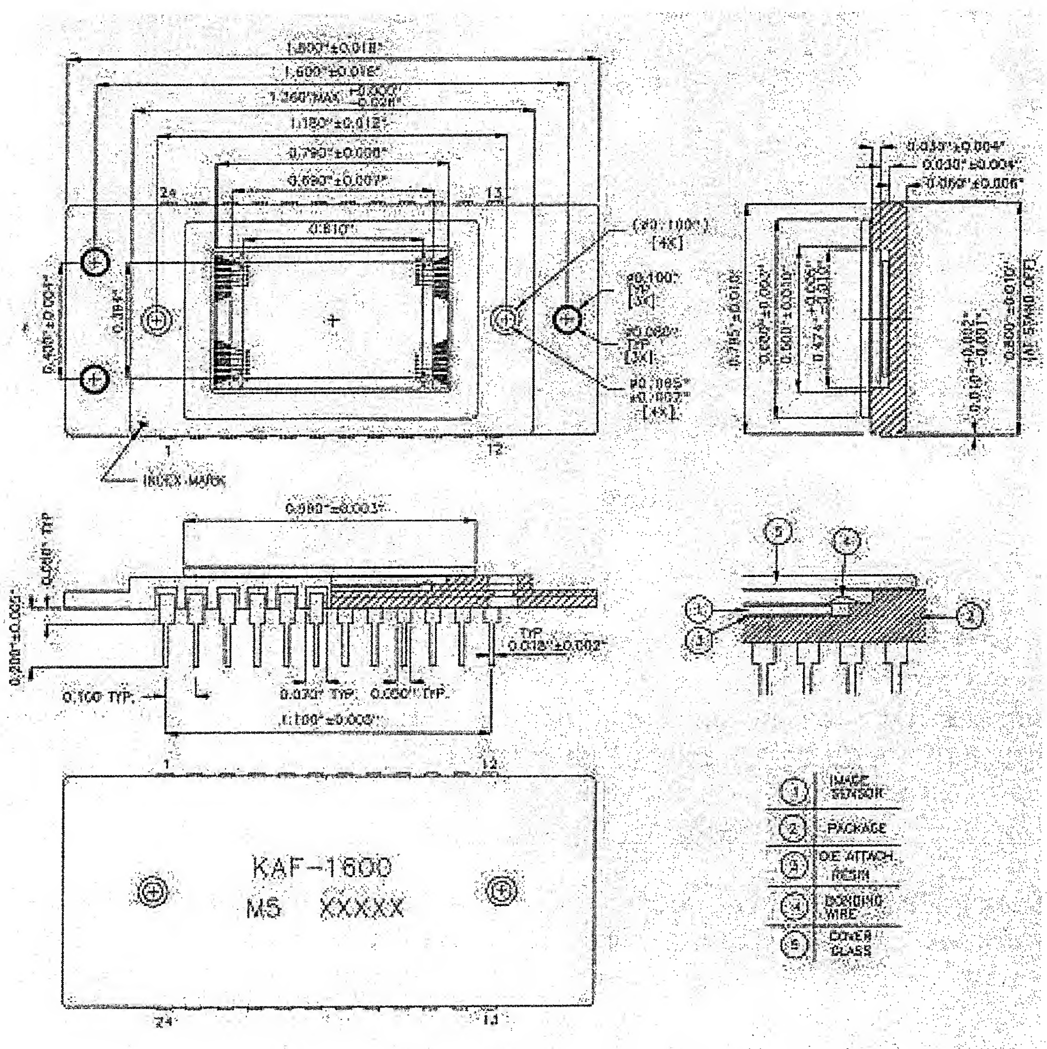


Figure 2. Package Drawing.

2.2 Pin Description

Pin	Symbol	Description	Pin	Symbol	Description
1	VOG	Output Gate	11, 12	N/C	No connection (open pin)
2	VOUT	Video Output	13	N/C	No connection (open pin)
3	VDD	Amplifier Supply	14	VSUB	Substrate (Ground)
4	VRD	Reset Drain	15, 16	ϕ_{V1}	Vertical CCD Clock - Phase 1
5	ϕR	Reset Clock	17, 18	ϕ_{V2}	Vertical CCD Clock - Phase 2
6	VSS	Amplifier Supply Return	19, 20	ϕ_{V2}	Vertical CCD Clock - Phase 2
7	ϕ_{H1}	Horizontal CCD Clock - Phase 1	21, 22	ϕ_{V1}	Vertical CCD Clock - Phase 1
8	ϕ_{H2}	Horizontal CCD Clock - Phase 2	23	Guard	Guard Ring
9, 10	N/C	No connection (open pin)	24	N/C	No Connection (open pin)

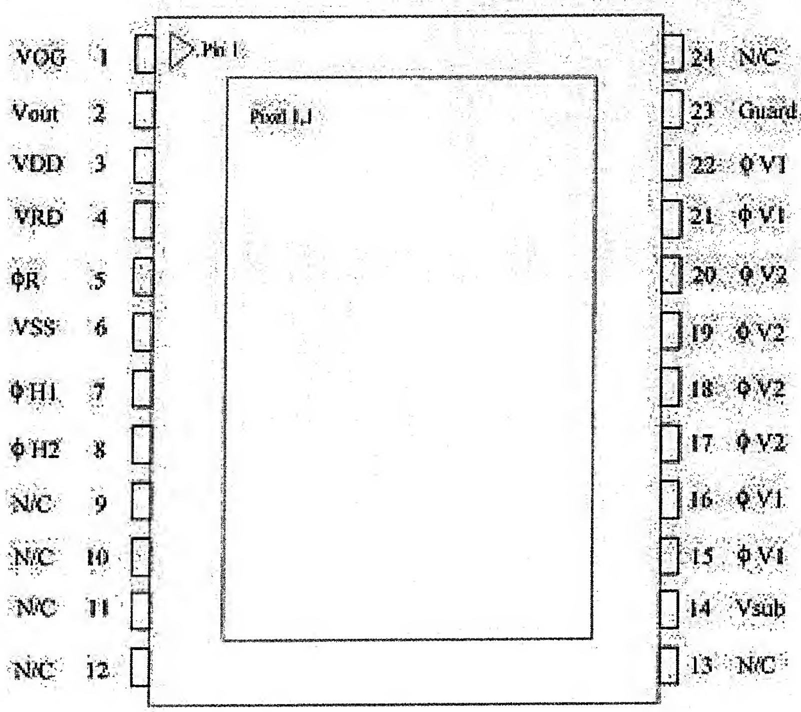


Figure 3. Packaging Pin Designations.

3.1 Absolute Maximum Ratings

Description	Symbol	Min.	Max.	Units	Notes
Diode Pin Voltages	Vdiode	0	20	V	1,2
Gate Pin Voltages - Type 1	Vgate1	-16	16	V	1,3
Gate Pin Voltages - Type 2	Vgate2	0	16	V	1,4
Inter-Gate Voltages	Vg-g		16	V	5
Output Bias Current	Iout		-10	mA	6
Output Load Capacitance	Cload		15	pF	6
Storage Temperature	T		100	°C	
Humidity	RH	5	90	%	7

Notes:

1. Referenced to pin VSUB.
2. Includes pins: VRD, VDD, VSS, VOUT.
3. Includes pins: ϕV1, ϕV2, ϕH1, ϕH2.
4. Includes pins: ϕR, VOG.
5. Voltage difference between overlapping gates. Includes: ϕV1 to ϕV2, ϕH1 to ϕH2, ϕV2 to ϕH1, ϕH2 to VOG.
6. Avoid shorting output pins to ground or any low impedance source during operation.
7. T=25°C. Excessive humidity will degrade MTTF.

Caution: **This device contains limited protection against Electrostatic Discharge (ESD). Devices should be handled in accordance with strict ESD protective procedures for Class 1 devices.**

3.2 DC Operating Conditions

Description	Symbol	Min.	Nom.	Max.	Units	Max. DC Current (mA)	Notes
Reset Drain	VRD	10.5	11	11.5	V	0.01	
Output Amplifier Return	VSS	1.5	2.0	2.5	V	-0.5	
Output Amplifier Supply	VDD	14.5	15	15.5	V	Iout	
Substrate	VSUB	0	0	0	V	0.01	
Output Gate	VOG	3.75	4	5	V	0.01	
Guard Ring	Guard	8.0	9.0	12.0	V	0.01	
Video Output Current	Iout		-5	-10	mA	-	1

Notes:

1. An output load sink must be applied to Vout to activate output amplifier - see Figure below.

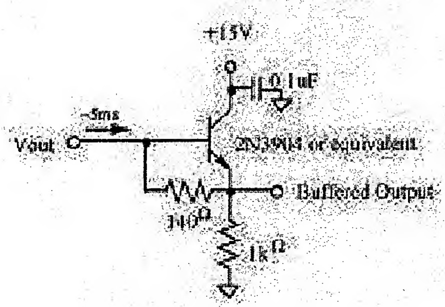


Figure 4. Recommended Output Structure Load Diagram.

3.3 AC Operating Conditions

Description	Symbol	Level	Min.	Nom.	Max.	Units	Effective Capacitance	Notes
Vertical CCD Clock - Phase 1	φV1	Low High	-8.5 0	-8.0 0.5	-7.5 1.0	V V	24nF (all fV1 pins)	
Vertical CCD Clock - Phase 2	φV2	Low High	-8.5 0	-8.0 0.5	-7.5 1.0	V V	24nF (all fV2 pins)	
Horizontal CCD Clock - Phase 1	φH1	Low High	-5.0 5.0	-4.0 6.0	-3.5 6.5	V V	100pF	
Horizontal CCD Clock - Phase 2	φH2	Low High	-5.0 5.0	-4.0 6.0	-3.5 6.5	V V	100pF	
Reset Clock	φR	Low High	-3.0 3.5	-4.0 2.0	-1.75 5.0	V V	5pF	

Notes:

1. All pins draw less than 10uA DC current.
2. Capacitance values relative to VSUB.

3.4 AC Timing Conditions

Description	Symbol	Min.	Nom.	Max.	Units	Notes
φH1, φH2 Clock Frequency	f_H		10	15	MHz	1, 2, 3
φV1, φV2 Clock Frequency	f_V		100	125	kHz	1, 2, 3
Pixel Period (1 Count)	t_e	67	100		ns	
φH1, φH2 Setup Time	$t_{\phi HS}$	0.5	1		μs	
φV1, φV2 Clock Pulse Width	$t_{\phi V}$	4	5		μs	2
Reset Clock Pulse Width	$t_{\phi R}$	10	20		ns	4
Readout Time	$t_{readout}$	121	178		ms	5
Integration Time	t_{int}					6
Line Time	t_{line}	117.4	172.5		μs	7

Notes:

1. 50% duty cycle values.
2. CTE may degrade above the nominal frequency.
3. Rise and fall times (10/90% levels) should be limited to 5-10% of clock period. Cross-over of register clocks should be between 40-60% of amplitude.
4. t_R should be clocked continuously.
5. $t_{readout} = (1032 * t_{line})$
6. Integration time is user specified. Longer integration times will degrade noise performance.
7. $t_{line} = (3 * t_{\phi V}) + t_{\phi HS} + (1564 * t_e) + t_e$

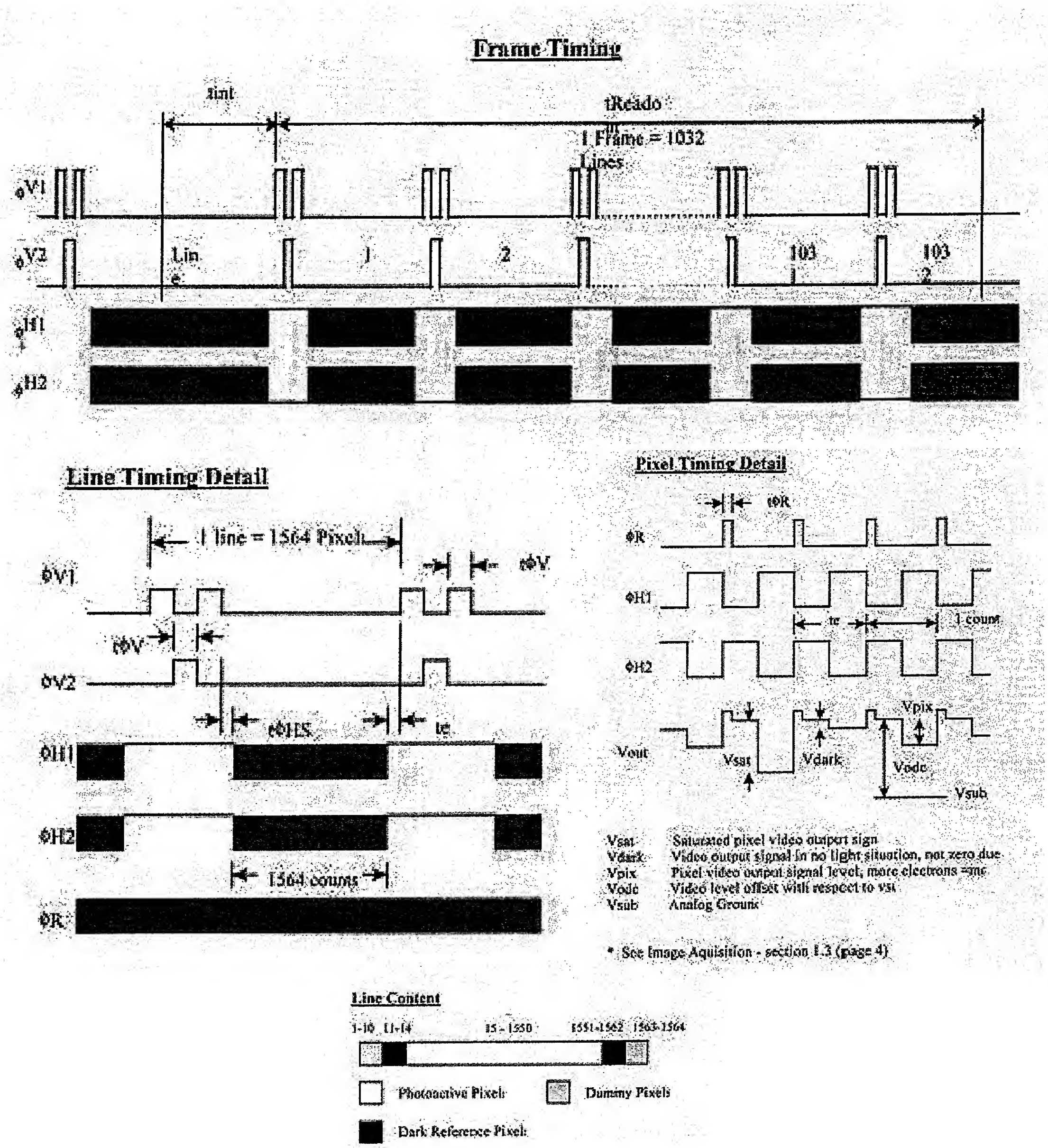


Figure 5. Timing Diagrams.

4.1 Performance Specifications

All values measured at 25°C, and nominal operating conditions. These parameters exclude defective pixels.

Description	Symbol	Min.	Nom.	Max.	Units	Notes
Saturation Signal Vertical CCD capacity Horizontal CCD capacity Output Node capacity	Nsat	85000 170000 190000	100000 200000 220000	120000 240000 240000	electrons / pixel	1
Red Quantum Efficiency (λ=650nm) Green Quantum Efficiency (λ =550nm) Blue Quantum Efficiency (λ=450nm)	Rr Rg Rb		35 35 12		% % %	
Photoresponse Non-Linearity	PRNL		1	2	%	2
Photoresponse Non-Uniformity	PRNU		1	3	%	3
Dark Signal	Jdark		15 3	30 10	electrons / pixel / sec pA/cm^2	4
Dark Signal Doubling Temperature		5	6	7	°C	
Dark Signal Non-Uniformity	DSNU		15	50	electrons / pixel / sec	5
Dynamic Range	DR	72	74		dB	6
Charge Transfer Efficiency	CTE	0.99995	0.99998			
Output Amplifier DC Offset	Vodc	9.5	10.5	11.5	V	7
Output Amplifier Bandwidth	f_{-3dB}		45		MHz	8
Output Amplifier Sensitivity	Vout/Ne-	9	10	11	uV/e-	
Output Amplifier output Impedance	Zout	175	200	250	Ohms	
Noise Floor	ne-		15	20	electrons	9

Notes:

1. For pixel binning applications, electron capacity up to 330000 can be achieved with modified CCD inputs. Each sensor may have to be optimized individually for these applications. Some performance parameters may be compromised to achieve the largest signals.

1. Worst case deviation from straight line fit, between 1% and 90% of Vsat.

2. One Sigma deviation of a 128x128 sample when CCD illuminated uniformly.

3. Average of all pixels with no illumination at 25 °C.

4. Average dark signal of any of 12 x 8 blocks within the sensor. (each block is 128 x 128 pixels)

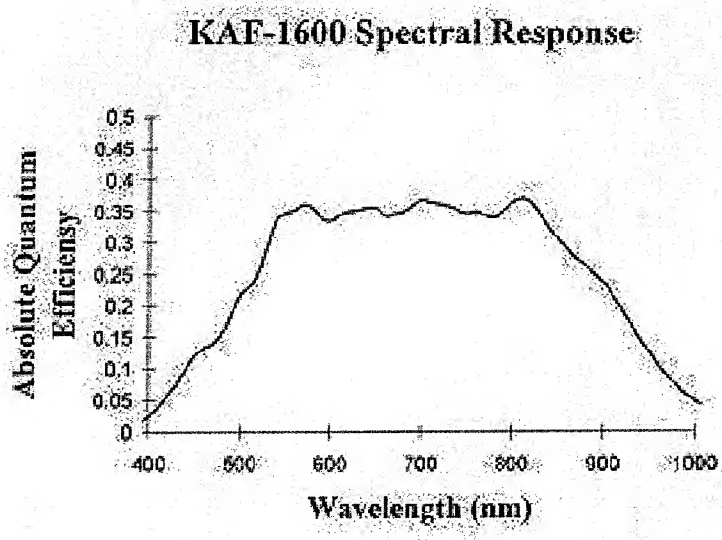
5. 20log (Nsat / ne-) at nominal operating frequency and 25 °C.

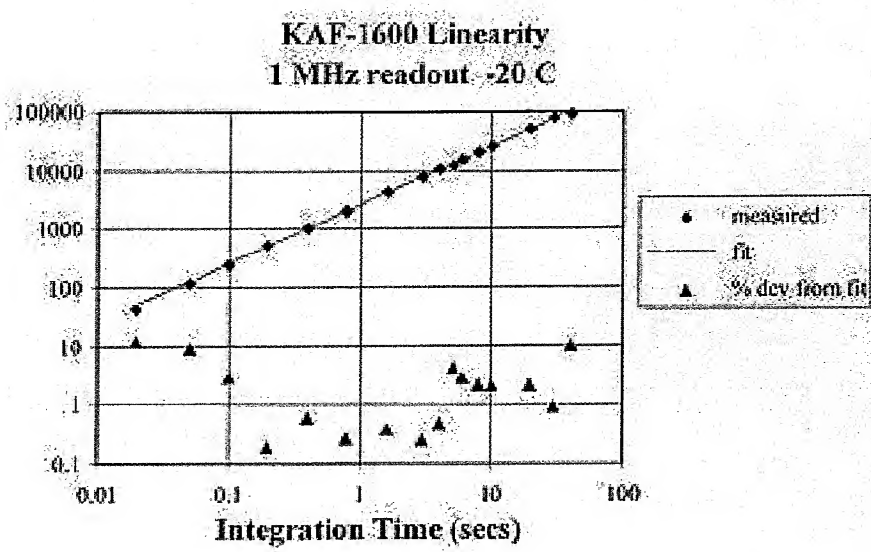
6. Video level offset with respect to ground

7. Last output amplifier stage only. Assumes 10pF off-chip load.

8. Output noise at 25 °C , nominal operating frequency, and Tint = 0.

4.2 Typical Performance Characteristics

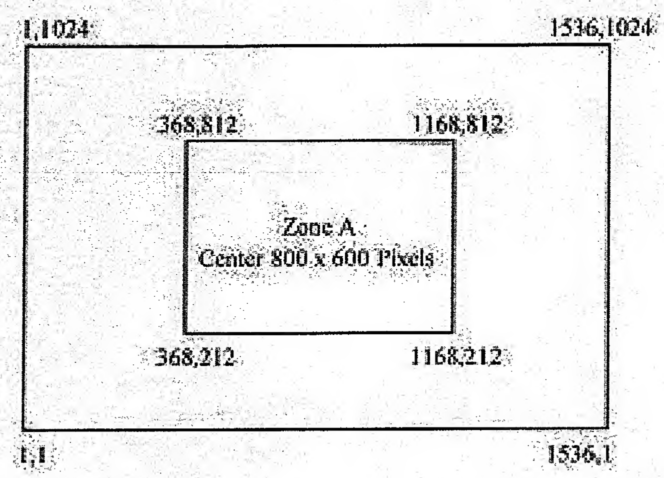




4.3 Defect Classification

Defect tests performed at T=25°C.

Class	Point Defects		Cluster Defects		Column Defects	
	Total	Zone A	Total	Zone A	Total	Zone A
C0	0	0	0	0	0	0
C1	≤5	≤2	0	0	0	0
C2	≤10	≤5	≤4	≤2	≤2	0
C3	≤20	≤10	≤8	≤4	≤4	≤2



Point Defect	DARK: A pixel which deviates by more than 6% from neighboring pixels when illuminated to 70% of saturation, OR BRIGHT: A Pixel with dark current > 5000 e/pixel/sec at 25C.
Cluster Defect	A grouping of not more than 5 adjacent point defects
Column Defect	A grouping of >5 contiguous point defects along a single column, OR A column containing a pixel with dark current > 12,000e/pixel/sec, OR A column that does not meet the minimum vertical CCD charge capacity, OR A column which loses more than 250 e under 2Ke illumination.
Neighboring pixels	The surrounding 128 x 128 pixels or ±64 columns/rows.
Defect Separation	Column and cluster defects are separated by no less than two (2) pixels in any direction (excluding single pixel defects).
Defect Region Exclusion	Defect region excludes the outer two (2) rows and columns at each side/end of the sensor.

5.1 Quality Assurance and Reliability

5.1.1 Quality Strategy: All devices will conform to the specifications stated in this document. This is accomplished through a combination of statistical process control and inspection at key points of the production process.

5.1.2 Replacement: All devices are warranted against failure in accordance with the terms of Terms of Sale.

5.1.3 Cleanliness: Devices are shipped free of contamination, scratches, etc. that would cause a visible defect.

5.1.4 ESD Precautions: Devices are shipped in a static-safe container and should only be handled at static-safe work stations.

5.1.5 Reliability: Information concerning the quality assurance and reliability testing procedures and results are available from the Microelectronics Technology Division and can be supplied upon request.

5.1.6 Test Data Retention: Devices have an identifying number of traceable to a test data file. Test data is kept for a period of 2 years after date of shipment.

5.2 Ordering Information

See Appendix E-1 (below) for available part numbers

Address all inquiries and purchase orders to:

Microelectronics Technology Division
Eastman Kodak Company
Rochester, New York 14650-2010
Phone: (716) 722-4385
Fax: (716) 477-4947

Kodak reserves the right to change any information contained herein without notice. All information furnished by Kodak is believed to be accurate.

Appendix E-1

Part Number Availability

Note: This appendix may be updated independently of the performance specification. Contact Eastman Kodak for the latest revision.

Device Name	Available Part Numbers	Features
KAF-1600	5B7033	Clear Taped Cover Glass, Class 0
KAF-1600	5B7400	Clear Taped Cover Glass, Class 1
KAF-1600	5B7401	Clear Taped Cover Glass, Class 2
KAF-1600	5B7402	Clear Taped Cover Glass, Class 3
KAF-1600	5B7403	Clear Taped Cover Glass, Engineering Grade
KAF-1600	5B7404	Clear Taped Cover Glass, Mechanical Grade
KAF-1600	5B7032	Clear Sealed Cover Glass, Class 0
KAF-1600	5B7211	Clear Sealed Cover Glass, Class 1
KAF-1600	5B7212	Clear Sealed Cover Glass, Class 2
KAF-1600	5B7213	Clear Sealed Cover Glass, Class 3
KAF-1600	5B7325	Clear Sealed Cover Glass, Engineering Grade
KAF-1600	5B7373	Clear Sealed Cover Glass, Mechanical Grade

Note: These devices are also available with UV phosphor coating and quartz cover glass. Contact Microelectronics Technology Division for details.

Appendix F. Laboratory Record Sheets

ADAR System Lab Test Sheet

Integrating Sphere Radiance Tests (radiance calibration & shutter linearity) Page 1 of ? (4/10/00)

Test Date
4/10/00

System under tes
* ✱ 5500
* ☐ 3000
* ☐ 1000
* ☐ Other:______

Serial Number
SN4

FICAS SW version: 3.1.9
FOS SW version: 2.1
Test Site: NASA SSC CIVL
Test Personnel: BENKELMAN, Thomas Nixon, Chris Schera, Dan Olive
egrating Sphere Calibration Data: 12" sphere; settings VARIABLE (see below)

Filename	Camera Serial #	Lens Serial #	Spectral Band	Exposure Time	Aperture	ISO	Int. Sphere Setting	Lens to exit aperture dist	UV haze Filter	Room Lights (ON/OFF)
sn4_lin_b1_99	420-9860	319268	450-515	1/400	f 2.8	200	35.6	1"	yes	off
frames 012 thru 021							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b1_99 #012-021; black cover on exit aperture:										
sn4_lin_b1_75	420-9860	319268	450-515	1/400	f 2.8	200	26.7	1"	yes	off
frames 32 thru 41							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b1_75 #032-041										
sn4_lin_b1_50	420-9860	319268	450-515	1/400	f 2.8	200	17.8	1"	yes	off
frames 42 through 51							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b1_50 #042-051										
sn4_lin_b1_25	420-9860	319268	450-515	1/400	f 2.8	200	8.9	1"	yes	off
frames 52 through 61							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b1_25 #052-061										
sn4_lin_b1_dark	420-9860	319268	450-515	1/400	f 2.8	200	DARK		yes	off
frames 62 through 71										
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b1_dk #062-071										

BEGIN EXPOSURE TIME TEST										
sn4_exp_b1_60.075 thru 084	420-9860	319268	450-515	1/60	f 2.8	200	6.0 mw/cm2-s	1"	yes	off
sn4_exp_b1_125.085 thru 094	420-9860	319268	450-515	1/125	f 2.8	200	6.0 mw/cm2-s	1"	yes	off
sn4_exp_b1_250.095 thru 104	420-9860	319268	450-515	1/250	f 2.8	200	6.0 mw/cm2-s	1"	yes	off
sn4_exp_b1_500.125 thru 134	420-9860	319268	450-515	1/500	f 2.8	200	6.0 mw/cm2-s	1"	yes	off
sn4_exp_b1_1000.135 thru 144	420-9860	319268	450-515	1/1000	f 2.8	200	6.0 mw/cm2-s	1"	yes	off
sn4_exp_b1_2000.145 thru 154	420-9860	319268	450-515	1/2000	f 2.8	200	6.0 mw/cm2-s	1"	yes	off

Chris took ASD data at beginning and end of this test: filenames sn4b1_ex .075 thru 084 (start) and 085 thru 094 (end)

Comments: 1) new (custom) filters from Omega Optical for NASA SDB contract.

2) This test to acquire data to correlate radiance to DN value

3) Numbers in filenames indicate approx % of full scale radiance (99% = "near maximum", 75 = 75% of previous setting, 25 = 25% of initial)

4) This test was run with software in LINEAR mode using the "longlinear.LUT" input LUT file.

5) Backscatter into integrating sphere tested with GER spectrometer: files saved as ?CONFIRM c:/GER/data/PosSysApr2k/cam1, with darl

6) This camera seems slightly more sensitive than band1 SN8; no explanation for WHY. Upper set of data shot at 1/320 (vs. 1/250 for SN8)

Full aperture on integrating sphere is 6.61 x 10exp1 mw/sr-cm-sq (max aperture, max integrated radiance for calibrated operation)

current through lamp is 5.569 amps; color temp of lamp 3008 kelvin

We have added a nitrogen purge to the integrating sphere to reduce humidity effects in the integrating sphere

ADAR System Lab Test Sheet

Integrating Sphere Radiance Tests (radiance calibration & shutter linearity) Page 2 of ? (4/10/00)

## Test Date ##	System under te:	Serial Number	
4/10/00	✱ 5500	SN4	FICAS SW version: 3.1.9
	☐ 3000		FOS SW version: 2.1
	☐ 1000		Test Site: NASA SSC CIVL
	☐ Other:______		Test Personnel: BENKELMAN, Chris Schera

egrating Sphere Calibration Data: 12" sphere; settings VARIABLE (see below)

Filename	Camera Serial #	Lens Serial #	Spectral Band	Exposure Time	Aperture	ISO	Int. Sphere Setting	Lens to exit aperture dist	UV haze Filter	Room Lights (ON/OFF)
sn4_lin_b2_99	420-9903	319270	525-605	1/1000	f 2.8	200	25	1"	yes	off
frames 160 thru 169							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b2_99 #160 - 169; black cover on exit aperture: fi										
sn4_lin_b2_75	420-9903	319270	525-605	1/1000	f 2.8	200	18.75	1"	yes	off
frames 180 thru 189							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b2_75#180 - 189										
sn4_lin_b2_50	420-9903	319270	525-605	1/1000	f 2.8	200	12.5	1"	yes	off
frames 190 thru 199							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b2_50 #190 - 199										
sn4_lin_b2_25	420-9903	319270	525-605	1/1000	f 2.8	200	6.25	1"	yes	off
frames 200 thru 209							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b2_25 #200 thru 209										
sn4_lin_b2_dark	420-9903	319270	525-605	1/1000	f 2.8	200	DARK	1"	yes	off
frames 210 thru 219										
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b2_dk # 210 thru 219										

BEGIN EXPOSURE TIME TEST										
sn4_exp_b2_60.225 thru 234	420-9903	319270	525-605	1/60	f 2.8	200	1.6	1"	yes	off
sn4_exp_b2_125.235 thru 244	420-9903	319270	525-605	1/125	f 2.8	200	same	1"	yes	off
sn4_exp_b2_250.245 thru 254	420-9903	319270	525-605	1/250	f 2.8	200	same	1"	yes	off
sn4_exp_b2_500.255 thru 264	420-9903	319270	525-605	1/500	f 2.8	200	same	1"	yes	off
sn4_exp_b2_1000.265 thru 274	420-9903	319270	525-605	1/1000	f 2.8	200	same	1"	yes	off
sn4_exp_b2_2000.275 thru 284	420-9903	319270	525-605	1/2000	f 2.8	200	same	1"	yes	off

Chris took ASD data at beginning and end of this test: sn4b2_ex.225 thru 234 (start) and 275 thru 284(end)

Comments: 1) new (custom) filters from Omega Optical for NASA SDB contract.

2) This test to acquire data to correlate radiance to DN value

3) Numbers in filenames indicate approx % of full scale radiance (99% = "near maximum", 75 = 75% of previous setting, 25 = 25% of initial)

4) This test was run with software in LINEAR mode using the "longlinear.LUT" input LUT file.

5) Backscatter into integrating sphere tested with GER spectrometer: files saved as ?CONFIRM c:/GER/data/PosSysApr2k/cam1, with dark c

6) This camera seems slightly more sensitive than band 1 SN8; no explanation for WHY. Upper set of data shot at 1/320 (vs. 1/250 for SN8) an

Full aperture on integrating sphere is 6.61 x 10exp1 mw/sr-cm-sq (max aperture, max integrated radiance for calibrated operation)

current through lamp is 5.569 amps; color temp of lamp 3008 kelvin

We have added a nitrogen purge to the integrating sphere to reduce humidity effects in the integrating sphere

ADAR System Lab Test Sheet

Integrating Sphere Radiance Tests (radiance calibration & shutter linearity)

## Test Date ##	System under test	Serial Number	
4/10/00	✱ 5500	SN4	FICAS SW version: 3.1.9
	☐ 3000		FOS SW version: 2.1
	☐ 1000		Test Site: NASA SSC CIVL
	☐ Other:______		Test Personnel: Cody Benkelman, Chris Schera

Integrating Sphere Calibration Data: 12" sphere; settings VARIABLE (see below)

Filename	Camera Serial #	Lens Serial #	Spectral Band	Exposure Time	Aperture	ISO	Int. Sphere Setting	Lens to exit aperture dist	UV haze Filter	Room Lights (ON/OFF)
sn4_lin_b3_99	420-9905	321470	630-690	1/1000	f 4	200	49	1"	yes	off
frames 290 - 299							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b3_99 #290 - 299; black cover on exit apertu										
sn4_lin_b3_75	420-9905	321470	630-690	1/1000	f 4	200	36.75	1"	yes	off
frames 340-349							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b3_75# 340-349										
sn4_lin_b3_50	420-9905	321470	630-690	1/1000	f 4	200	24.5	1"	yes	off
frames 350-359							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b2_50 #350-359										
sn4_lin_b3_25	420-9905	321470	630-690	1/1000	f 4	200	12.25	1"	yes	off
frames 360-369							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b2_25 #360-369										
sn4_lin_b3_dark	420-9905	321470	630-690	1/1000	f 4	200	DARK	1"	yes	off
frames 370 - 379										
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b2_dk # 370 - 379										

BEGIN EXPOSURE TIME TEST										
sn4_exp_b3_60.385-394	420-9905	321470	630-690	1/60	f 4	200	3.0 mw/cm2-s	1"	yes	off
sn4_exp_b3_125.395-404	420-9905	321470	630-690	1/125	f 4	200	same	1"	yes	off
sn4_exp_b3_125.405-414	420-9905	321470	630-690	1/250	f 4	200	same	1"	yes	off
sn4_exp_b3_500.417 thru 426	420-9905	321470	630-690	1/500	f 4	200	same	1"	yes	off
sn4_exp_b3_1000.427-436	420-9905	321470	630-690	1/1000	f 4	200	same	1"	yes	off
sn4_exp_b2_2000.443 - 452	420-9905	321470	630-690	1/2000	f 4	200	same	1"	yes	off

Chris took ASD data at beginning and end of this test: sn4b3_ex.385 thru 394 (start) and 443 thru 452(end)

Comments: 1) new (custom) filters from Omega Optical for NASA SDB contract.

2) This test to acquire data to correlate radiance to DN value

3) Numbers in filenames indicate approx % of full scale radiance (99% = "near maximum", 75 = 75% of previous setting, 25 = 25% of initial

4) This test was run with software in LINEAR mode using the "longlinear.LUT" input LUT file.

5) Backscatter into integrating sphere tested with GER spectrometer: files saved as ?CONFIRM c:/GER/data/PosSysApr2k/cam1, with da

6) This camera seems slightly more sensitive than band1 SN8; no explanation for WHY. Upper set of data shot at 1/320 (vs. 1/250 for SN8

Full aperture on integrating sphere is 6.61 x 10exp1 mw/sr-cm-sq (max aperture, max integrated radiance for calibrated operation)

current through lamp is 5.569 amps; color temp of lamp 3008 kelvin

We have added a nitrogen purge to the integrating sphere to reduce humidity effects in the integrating sphere

ADAR System Lab Test Sheet

Integrating Sphere Radiance Tests (radiance calibration & shutter linearity)

Test Date
4/11/00

System under test:
- [x] 5500
- [ ] 3000
- [ ] 1000
- [ ] Other:______

Serial Number: SN4

FICAS SW version: 3.1.9
FOS SW version: 2.1
Test Site: NASA SSC CIVL
Test Personnel: Cody Benkelman, Thomas Nixon
Integrating Sphere Calibration Data: 12" sphere; settings VARIABLE (see below)

Filename	Camera Serial #	Lens Serial #	Spectral Band	Exposure Time	Aperture	ISO	Int. Sphere Setting	Lens to exit aperture dist	UV haze Filter	Room Lights (ON/OFF)
sn4_lin_b4_99	420-9912	L321697	750-900	1/1000	f 5.6	200	31	1"	yes	off
frames 012 - 021							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000411/sn4b4_99 #12-21; black cover on exit aperture: file										
sn4_lin_b4_75	420-9912	L321697	750-900	1/1000	f 5.6	200	23.25	1"	yes	off
frames 32-41							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b4_75# 32-41										
sn4_lin_b4_50	420-9912	L321697	750-900	1/1000	f 5.6	200	15.5	1"	yes	off
frames 52-61							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b2_50 # 52-61										
sn4_lin_b4_25	420-9912	L321697	750-900	1/1000	f 5.6	200	7.75	1"	yes	off
frames 62-71							mw/cm^2-sr			
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b2_25 # 62-71										
sn4_lin_b4_dark	420-9912	L321697	750-900	1/1000	f 5.6	200	DARK	1"	yes	off
frames 72-81										
ASD files for back reflectance test: FILTER facing exit aperture: files named Possys/000410/sn4b2_dk # 72-81										

BEGIN EXPOSURE TIME TEST										
sn4_exp_b4_60.091-100	420-9912	L321697	750-900	1/60	f 5.6	200	1.95 mw/cm2-sr	1"	yes	off
sn4_exp_b4_125.101-110	420-9912	L321697	750-900	1/125	f 5.6	200	1.95 mw/cm2-sr	1"	yes	off
sn4_exp_b4_250.111-120	420-9912	L321697	750-900	1/250	f 5.6	200	1.95 mw/cm2-sr	1"	yes	off
sn4_exp_b4_500.121-130	420-9912	L321697	750-900	1/500	f 5.6	200	1.95 mw/cm2-sr	1"	yes	off
sn4_exp_b4_1000.131-140	420-9912	L321697	750-900	1/1000	f 5.6	200	1.95 mw/cm2-sr	1"	yes	off
sn4_exp_b4_2000.141-150	420-9912	L321697	750-900	1/2000	f 5.6	200	1.95 mw/cm2-sr	1"	yes	off

Thomas took ASD data at beginning and end of this test: sn4b4_ex.091-100 (start) and 141-150 (end)

Comments: 1) new (custom) filters from Omega Optical for NASA SDB contract.

2) This test to acquire data to correlate radiance to DN value

3) Numbers in filenames indicate approx % of full scale radiance (99% = "near maximum", 75 = 75% of previous setting, 25 = 25% of initial)

4) This test was run with software in LINEAR mode using the "longlinear.LUT" input LUT file.

5) Backscatter into integrating sphere tested with GER spectrometer: files saved as ?CONFIRM c:/GER/data/PosSysApr2k/cam1, with dark

6) This camera seems slightly more sensitive than band1 SN8; no explanation for WHY. Upper set of data shot at 1/320 (vs. 1/250 for SN8) a

Full aperture on integrating sphere is 6.61 x 10exp1 mw/sr-cm-sq (max aperture, max integrated radiance for calibrated operation)

current through lamp is 5.569 amps; color temp of lamp 3008 kelvin

We have added a nitrogen purge to the integrating sphere to reduce humidity effects in the integrating sphere

ADAR System Lab Test Sheet

Full system spectral response test

## Test Date ##	System under test:	Serial Number	
4/11/00	✱ 5500	SN4	FICAS SW version: 3.1.9
	☐ 3000		FOS SW version: 2.1
	☐ 1000		Test Site: NASA SSC
	☐ Other:______		Test Personnel: Cody Benkelman, Thomas Nixon

Integrating Sphere Calibration Data: 4" sphere illum. w/ monochromator & sampled with ASD spectrometer

File basename	file #'s	Camera Serial #	Lens Serial #	Spectral Band	Exposure Time	Aperture	ISO	Monochromator band center	ASD file basename	ASD file #'s	Lens to exit aperture dist	onochromat bandwidth	onochromat slit width	Which Grating?	Room Lights (ON/OFF)
SHOOT 5 OR 10 FRAMES IF POSSIBLE; SEE HOW LONG THIS TAKES...															
sn4_b1_spectrum	156-160	420-9860	319268	450-515	1/2 sec	f 2.8	200	405	sn4b1spc	156-160	2"	1.8	2 mm	1	off
sn4_b1_spectrum	161-165	420-9860	319268	450-515	1/2 sec	f 2.8	200	410	sn4b1spc	161-165	2"	1.8	2 mm	1	off
sn4_b1_spectrum	166-170	420-9860	319268	450-515	1/2 sec	f 2.8	200	415	sn4b1spc	166-170	2"	1.8	2 mm	1	off
sn4_b1_spectrum	171-175	420-9860	319268	450-515	1/2 sec	f 2.8	200	420	sn4b1spc	171-175	2"	1.8	2 mm	1	off
sn4_b1_spectrum	176-180	420-9860	319268	450-515	1/2 sec	f 2.8	200	425	sn4b1spc	176-180	2"	1.8	2 mm	1	off
sn4_b1_spectrum	181-185	420-9860	319268	450-515	1/2 sec	f 2.8	200	430	sn4b1spc	181-185	2"	1.8	2 mm	1	off
sn4_b1_spectrum	186-190	420-9860	319268	450-515	1/2 sec	f 2.8	200	435	sn4b1spc	186-190	2"	1.8	2 mm	1	off
sn4_b1_spectrum	191-195	420-9860	319268	450-515	1/2 sec	f 2.8	200	440	sn4b1spc	191-195	2"	1.8	2 mm	1	off
sn4_b1_spectrum	196-200	420-9860	319268	450-515	1/2 sec	f 2.8	200	445	sn4b1spc	196-200	2"	1.8	2 mm	1	off
sn4_b1_spectrum	201-205	420-9860	319268	450-515	1/2 sec	f 2.8	200	450	sn4b1spc	201-205	2"	1.8	2 mm	1	off
sn4_b1_spectrum	206-210	420-9860	319268	450-515	1/2 sec	f 2.8	200	455	sn4b1spc	206-210	2"	1.8	2 mm	1	off
sn4_b1_spectrum	211-215	420-9860	319268	450-515	1/2 sec	f 2.8	200	460	sn4b1spc	211-215	2"	1.8	2 mm	1	off
sn4_b1_spectrum	216-220	420-9860	319268	450-515	1/2 sec	f 2.8	200	465	sn4b1spc	216-220	2"	1.8	2 mm	1	off
sn4_b1_spectrum	221-225	420-9860	319268	450-515	1/2 sec	f 2.8	200	470	sn4b1spc	221-225	2"	1.8	2 mm	1	off
sn4_b1_spectrum	226-230	420-9860	319268	450-515	1/2 sec	f 2.8	200	475	sn4b1spc	226-230	2"	1.8	2 mm	1	off
sn4_b1_spectrum	231-235	420-9860	319268	450-515	1/2 sec	f 2.8	200	480	sn4b1spc	231-235	2"	1.8	2 mm	1	off
sn4_b1_spectrum	241-245	420-9860	319268	450-515	1/2 sec	f 2.8	200	485	sn4b1spc	241-245	2"	1.8	2 mm	1	off
sn4_b1_spectrum	246-250	420-9860	319268	450-515	1/2 sec	f 2.8	200	490	sn4b1spc	246-250	2"	1.8	2 mm	1	off
sn4_b1_spectrum	251-255	420-9860	319268	450-515	1/2 sec	f 2.8	200	495	sn4b1spc	251-255	2"	1.8	2 mm	1	off
sn4_b1_spectrum	256-260	420-9860	319268	450-515	1/2 sec	f 2.8	200	500	sn4b1spc	256-260	2"	1.8	2 mm	1	off
sn4_b1_spectrum	261-265	420-9860	319268	450-515	1/2 sec	f 2.8	200	505	sn4b1spc	261-265	2"	1.8	2 mm	1	off

sn4_b1_spectrum 266-270	420-9860	319268	450-515	1/2 sec	f 2.8	200	510	sn4b1spc	266-270	2"	1.8	2 mm	1	off
sn4_b1_spectrum 271-275	420-9860	319268	450-515	1/2 sec	f 2.8	200	515	sn4b1spc	271-275	2"	1.8	2 mm	1	off
sn4_b1_spectrum 276-280	420-9860	319268	450-515	1/2 sec	f 2.8	200	520	sn4b1spc	276-280	2"	1.8	2 mm	1	off
sn4_b1_spectrum 281-285	420-9860	319268	450-515	1/2 sec	f 2.8	200	525	sn4b1spc	281-285	2"	1.8	2 mm	1	off
sn4_b1_spectrum 286-290	420-9860	319268	450-515	1/2 sec	f 2.8	200	530	sn4b1spc	286-290	2"	1.8	2 mm	1	off
sn4_b1_spectrum 291-295	420-9860	319268	450-515	1/2 sec	f 2.8	200	535	sn4b1spc	291-295	2"	1.8	2 mm	1	off
sn4_b1_spectrum 296-300	420-9860	319268	450-515	1/2 sec	f 2.8	200	540	sn4b1spc	296-300	2"	1.8	2 mm	1	off
sn4_b1_spectrum 301-305	420-9860	319268	450-515	1/2 sec	f 2.8	200	545	sn4b1spc	301-305	2"	1.8	2 mm	1	off
sn4_b1_spectrum 306-310	420-9860	319268	450-515	1/2 sec	f 2.8	200	550	sn4b1spc	306-310	2"	1.8	2 mm	1	off
sn4_b1_spectrum 311-315	420-9860	319268	450-515	1/2 sec	f 2.8	200	555	sn4b1spc	311-315	2"	1.8	2 mm	1	off
sn4_b1_spectrum 316-320	420-9860	319268	450-515	1/2 sec	f 2.8	200	560	sn4b1spc	316-320	2"	1.8	2 mm	1	off
sn4_b1_spectrum 321-325	420-9860	319268	450-515	1/2 sec	f 2.8	200	565	sn4b1spc	321-325	2"	1.8	2 mm	1	off
sn4_b1_spectrum 326-330	420-9860	319268	450-515	1/2 sec	f 2.8	200	570	sn4b1spc	326-330	2"	1.8	2 mm	1	off
sn4_b1_spectrum 331-335	420-9860	319268	450-515	1/2 sec	f 2.8	200	DARK	sn4b1spc	331-335	2"	1.8	2 mm	1	off

Comments: 1) new (custom) filters from Omega Optical for NASA SDB contract.

2) This test to acquire data to correlate radiance to DN value as a function of input wavelength

3) Camera in LINEAR mode

4) GRATING #2 used for band 4, grating #1 for bands 1, 2 & 3 averaging 25 scans per reading on the ASD

5) ASD files stored in directory "FR/possys/000411/" on CIV Lab's ASD (had to SWITCH to a different unit for cameras 2 & 3)

ADAR System lab Test Sheet
Full system spectral response test

under test: | Serial Number SN4 | RCAS SW version: 3.1.9
5500 | FOS SW version: 2.1
3000 | Test Site: NASA SSC
1000 | Test Personnel: Cody Benkelman, Thomas Nixon
Other:______

Integrating Sphere Calibration Data: 4" sphere illum w/ monochromator & sampled with ASD spectrometer

Camera Serial #	Lens Serial #	Spectral Band	Exposure Time	Aperture	ISO	Monochromator band center	ASD file basename	ASD file #'s	Lens to exit aperture dist	onochromat bandwidth	onochromat slit width	Which Grating?	Room Lights (ON/OFF)
420-9912	L321697	750-900	1/2 sec	f 5.6	200	DARK	sn4b1spc*	341-345	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	700	sn4b1spc*	346-350	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	705	sn4b1spc*	351-355	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	710	sn4b1spc*	356-360	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	715	sn4b1spc*	361-365	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	720	sn4b1spc*	366-370	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	725	sn4b1spc*	371-375	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	730	sn4b1spc*	376-380	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	735	sn4b1spc*	381-385	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	740	sn4b1spc*	386-390	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	745	sn4b1spc*	391-395	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	750	sn4b1spc*	396-400	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	755	sn4b1spc*	401-405	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	760	sn4b1spc*	406-410	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	765	sn4b1spc*	411-415	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	770	sn4b1spc*	416-420	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	775	sn4b1spc*	421-425	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	780	sn4b1spc*	426-430	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	785	sn4b1spc*	431-435	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	790	sn4b1spc*	436-440	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	795	sn4b1spc*	441-445	2"	4 nm	1250 microns	#2	off

420-9912	L321697	750-900	1/2 sec	f 5.6	200	800	sn4b1spc*	446-450	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	805	sn4b1spc*	451-455	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	810	sn4b1spc*	456-460	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	815	sn4b1spc*	461-465	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	820	sn4b1spc*	466-470	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	825	sn4b1spc*	471-475	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	830	sn4b1spc*	476-480	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	835	sn4b1spc*	481-485	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	840	sn4b1spc*	486-490	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	845	sn4b1spc*	491-495	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	850	sn4b1spc*	496-500	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	855	sn4b1spc*	501-505	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	860	sn4b1spc*	506-510	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	865	sn4b1spc*	511-515	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	870	sn4b4spc	516-520	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	875	sn4b4spc	521-525	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	880	sn4b4spc	526-530	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	885	sn4b4spc	531-535	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	890	sn4b4spc	536-540	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	895	sn4b4spc	541-545	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	900	sn4b4spc	546-550	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	905	sn4b4spc	551-555	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	910	sn4b4spc	556-560	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	915	sn4b4spc	561-565	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	920	sn4b4spc	566-570	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	925	sn4b4spc	571-575	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	930	sn4b4spc	576-580	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	935	sn4b4spc	581-585	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	940	sn4b4spc	586-590	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	945	sn4b4spc	591-595	2"	4 nm	1250 microns	#2	off
420-9912	L321697	750-900	1/2 sec	f 5.6	200	950	sn4b4spc	596-600	2"	4 nm	1250 microns	#2	off

rr) filters from Omega Optical for NASA SDB contract.

ıata to correlate radiance to DN value as a function of input wavelength

ıode

r band 4, grating #1 for bands 1, 2 & 3 averaging 25 scans per reading on the ASD

rectory "FR/possys/000411/" on CIV Lab's ASD (had to SWITCH to a different unit for cameras 2 & 3)

ng error up to file number 416

ADAR System Lab Test Sheet

Full system spectral response test

Test Date
4/11/00

System under test:
- ✱ 5500
- ☐ 3000
- ☐ 1000
- ☐ Other:______

Serial Number: SN4

FCAS SW version: 3.1.9
FOS SW version: 2.1
Test Site: NASA SSC
Test Personnel: Cody Benkelman, Chris Schera
Integrating Sphere Calibration Data: 4" sphere illum. w/ monochromator & sampled with ASD spectrometer

File basename	file #'s	Camera Serial #	Lens Serial #	Spectral Band	Exposure Time	Aperture	ISO	Monochromator band center	ASD file basename	ASD file #	Lens to exit aperture dist	onochromat bandwidth	onochromat slit width	Which Grating?	Room Lights (ON/OFF)
sn4_b2_spectrum	011-015	420-9903	319270	525-605	1/2 sec	f 2.8	200	DARK	sn4b2spc	011-015	2"	1.8	2 mm	1	off
sn4_b2_spectrum	016-020	420-9903	319270	525-605	1/2 sec	f 2.8	200	480	sn4b2spc	016-020	2"	1.8	2 mm	1	off
sn4_b2_spectrum	021-025	420-9903	319270	525-605	1/2 sec	f 2.8	200	485	sn4b2spc	021-025	2"	1.8	2 mm	1	off
sn4_b2_spectrum	026-030	420-9903	319270	525-605	1/2 sec	f 2.8	200	490	sn4b2spc	026-030	2"	1.8	2 mm	1	off
sn4_b2_spectrum	031-035	420-9903	319270	525-605	1/2 sec	f 2.8	200	495	sn4b2spc	031-035	2"	1.8	2 mm	1	off
sn4_b2_spectrum	036-040	420-9903	319270	525-605	1/2 sec	f 2.8	200	500	sn4b2spc	036-040	2"	1.8	2 mm	1	off
sn4_b2_spectrum	041-045	420-9903	319270	525-605	1/2 sec	f 2.8	200	505	sn4b2spc	041-045	2"	1.8	2 mm	1	off
sn4_b2_spectrum	046-050	420-9903	319270	525-605	1/2 sec	f 2.8	200	510	sn4b2spc	046-050	2"	1.8	2 mm	1	off
sn4_b2_spectrum	052-055	420-9903	319270	525-605	1/2 sec	f 2.8	200	515	sn4b2spc	052-055	2"	1.8	2 mm	1	off
sn4_b2_spectrum	056-060	420-9903	319270	525-605	1/2 sec	f 2.8	200	520	sn4b2spc	056-060	2"	1.8	2 mm	1	off
sn4_b2_spectrum	061-065	420-9903	319270	525-605	1/2 sec	f 2.8	200	525	sn4b2spc	061-065	2"	1.8	2 mm	1	off
sn4_b2_spectrum	066-070	420-9903	319270	525-605	1/2 sec	f 2.8	200	530	sn4b2spc	066-070	2"	1.8	2 mm	1	off
sn4_b2_spectrum	071-075	420-9903	319270	525-605	1/2 sec	f 2.8	200	535	sn4b2spc	071-075	2"	1.8	2 mm	1	off
sn4_b2_spectrum	076-080	420-9903	319270	525-605	1/2 sec	f 2.8	200	540	sn4b2spc	076-080	2"	1.8	2 mm	1	off
sn4_b2_spectrum	081-085	420-9903	319270	525-605	1/2 sec	f 2.8	200	545	sn4b2spc	081-085	2"	1.8	2 mm	1	off
sn4_b2_spectrum	086-090	420-9903	319270	525-605	1/2 sec	f 2.8	200	550	sn4b2spc	086-090	2"	1.8	2 mm	1	off
sn4_b2_spectrum	091-095	420-9903	319270	525-605	1/2 sec	f 2.8	200	555	sn4b2spc	091-095	2"	1.8	2 mm	1	off
sn4_b2_spectrum	096-100	420-9903	319270	525-605	1/2 sec	f 2.8	200	560	sn4b2spc	096-100	2"	1.8	2 mm	1	off
sn4_b2_spectrum	101-105	420-9903	319270	525-605	1/2 sec	f 2.8	200	565	sn4b2spc	101-105	2"	1.8	2 mm	1	off
sn4_b2_spectrum	106-110	420-9903	319270	525-605	1/2 sec	f 2.8	200	570	sn4b2spc	106-110	2"	1.8	2 mm	1	off
sn4_b2_spectrum	111-115	420-9903	319270	525-605	1/2 sec	f 2.8	200	575	sn4b2spc	111-115	2"	1.8	2 mm	1	off

sn4_b2_spectrum 116-120	420-9903	319270	525-605	1/2 sec	f 2.8	200	580	sn4b2spc	116-120	2"	1.8	2 mm	1	off
sn4_b2_spectrum 121-125	420-9903	319270	525-605	1/2 sec	f 2.8	200	585	sn4b2spc	121-125	2"	1.8	2 mm	1	off
sn4_b2_spectrum 126-130	420-9903	319270	525-605	1/2 sec	f 2.8	200	590	sn4b2spc	126-130	2"	1.8	2 mm	1	off
sn4_b2_spectrum 131-135	420-9903	319270	525-605	1/2 sec	f 2.8	200	595	sn4b2spc	131-135	2"	1.8	2 mm	1	off
sn4_b2_spectrum 136-140	420-9903	319270	525-605	1/2 sec	f 2.8	200	600	sn4b2spc	136-140	2"	1.8	2 mm	1	off
sn4_b2_spectrum 141-145	420-9903	319270	525-605	1/2 sec	f 2.8	200	605	sn4b2spc	141-145	2"	1.8	2 mm	1	off
sn4_b2_spectrum 151-155	420-9903	319270	525-605	1/2 sec	f 2.8	200	610	sn4b2spc	151-155	2"	1.8	2 mm	1	off
sn4_b2_spectrum 156-160	420-9903	319270	525-605	1/2 sec	f 2.8	200	615	sn4b2spc	156-160	2"	1.8	2 mm	1	off
sn4_b2_spectrum 161-165	420-9903	319270	525-605	1/2 sec	f 2.8	200	620	sn4b2spc	161-165	2"	1.8	2 mm	1	off
sn4_b2_spectrum 166-170	420-9903	319270	525-605	1/2 sec	f 2.8	200	625	sn4b2spc	166-170	2"	1.8	2 mm	1	off
sn4_b2_spectrum 171-175	420-9903	319270	525-605	1/2 sec	f 2.8	200	630	sn4b2spc	171-175	2"	1.8	2 mm	1	off
sn4_b2_spectrum 176-180	420-9903	319270	525-605	1/2 sec	f 2.8	200	635	sn4b2spc	176-180	2"	1.8	2 mm	1	off
sn4_b2_spectrum 181-185	420-9903	319270	525-605	1/2 sec	f 2.8	200	640	sn4b2spc	181-185	2"	1.8	2 mm	1	off

Comments: 1) new (custom) filters from Omega Optical for NASA SDB contract.

2) This test to acquire data to correlate radiance to DN value as a function of input wavelength

3) Camera in LINEAR mode

4) GRATING #2 used for band 4, grating #1 for bands 1, 2 & 3 averaging 25 scans per reading on the ASD

5) ASD files stored in directory "FR/possys/000411/" on ASD #669

ADAR System Lab Test Sheet
Full system spectral response test

Test Date
4/11/00

System under test:
* ✱ 5500
* ☐ 3000
* ☐ 1000
* ☐ Other:______

Serial Number
SN4

FICAS SW version: 3.1.9
FOS SW version: 2.1
Test Site: NASA SSC
Test Personnel: Cody Benkelman, Chris Schera
Integrating Sphere Calibration Data: 4" sphere illum. w/ monochromator & sampled with ASD spectrometer

File basename	file #'s	Camera Serial #	Lens Serial #	Spectral Band	Exposure Time	Aperture	ISO	Monochromator band center	ASD file basename	ASD file #	Lens to exit aperture dist	onochromat bandwidth	onochromat slit width	Which Grating?	Room Lights (ON/OFF)
sn4_b3_spectrum	201-205	420-9905	321470	630-690	1/2 sec	f 4	200	DARK	sn4b3spc	201-205	2"	1.8	2 mm	1	off
sn4_b3_spectrum	206-210	420-9905	321470	630-690	1/2 sec	f 4	200	590	sn4b3spc	206-210	2"	1.8	2 mm	1	off
sn4_b3_spectrum	211-215	420-9905	321470	630-690	1/2 sec	f 4	200	595	sn4b3spc	211-215	2"	1.8	2 mm	1	off
sn4_b3_spectrum	216-220	420-9905	321470	630-690	1/2 sec	f 4	200	600	sn4b3spc	216-220	2"	1.8	2 mm	1	off
sn4_b3_spectrum	221-225	420-9905	321470	630-690	1/2 sec	f 4	200	605	sn4b3spc	221-225	2"	1.8	2 mm	1	off
sn4_b3_spectrum	226-230	420-9905	321470	630-690	1/2 sec	f 4	200	610	sn4b3spc	226-230	2"	1.8	2 mm	1	off
sn4_b3_spectrum	231-235	420-9905	321470	630-690	1/2 sec	f 4	200	615	sn4b3spc	231-235	2"	1.8	2 mm	1	off
sn4_b3_spectrum	236-240	420-9905	321470	630-690	1/2 sec	f 4	200	620	sn4b3spc	236-240	2"	1.8	2 mm	1	off
sn4_b3_spectrum	241-245	420-9905	321470	630-690	1/2 sec	f 4	200	625	sn4b3spc	241-245	2"	1.8	2 mm	1	off
sn4_b3_spectrum	246-250	420-9905	321470	630-690	1/2 sec	f 4	200	630	sn4b3spc	246-250	2"	1.8	2 mm	1	off
sn4_b3_spectrum	251-255	420-9905	321470	630-690	1/2 sec	f 4	200	635	sn4b3spc	251-255	2"	1.8	2 mm	1	off
sn4_b3_spectrum	256-260	420-9905	321470	630-690	1/2 sec	f 4	200	640	sn4b3spc	256-260	2"	1.8	2 mm	1	off
sn4_b3_spectrum	261-265	420-9905	321470	630-690	1/2 sec	f 4	200	645	sn4b3spc	261-265	2"	1.8	2 mm	1	off
sn4_b3_spectrum	266-270	420-9905	321470	630-690	1/2 sec	f 4	200	650	sn4b3spc	266-270	2"	1.8	2 mm	1	off
sn4_b3_spectrum	271-275	420-9905	321470	630-690	1/2 sec	f 4	200	655	sn4b3spc	271-275	2"	1.8	2 mm	1	off
sn4_b3_spectrum	276-280	420-9905	321470	630-690	1/2 sec	f 4	200	660	sn4b3spc	276-280	2"	1.8	2 mm	1	off
sn4_b3_spectrum	281-285	420-9905	321470	630-690	1/2 sec	f 4	200	665	sn4b3spc	281-285	2"	1.8	2 mm	1	off
sn4_b3_spectrum	286-290	420-9905	321470	630-690	1/2 sec	f 4	200	670	sn4b3spc	286-290	2"	1.8	2 mm	1	off
sn4_b3_spectrum	291-295	420-9905	321470	630-690	1/2 sec	f 4	200	675	sn4b3spc	291-295	2"	1.8	2 mm	1	off
sn4_b3_spectrum	*296-300*	*420-9905*	*321470*	*630-690*	*1/2 sec*	*f 4*	*200*	*680*	*sn4b3spc*	*296-300*	2"	1.8	2 mm	1	off
sn4_b3_spectrum	*301-305*	*420-9905*	*321470*	*630-690*	*1/2 sec*	*f 4*	*200*	*680*	*sn4b3spc*	*301-305*	2"	1.8	2 mm	1	off

sn4_b3_spectrum 306-310	420-9905	321470	630-690	1/2 sec	f 4	200	685	sn4b3spc	306-310	2"	1.8	2 mm	1	off
sn4_b3_spectrum 311-315	420-9905	321470	630-690	1/2 sec	f 4	200	690	sn4b3spc	311-315	2"	1.8	2 mm	1	off
sn4_b3_spectrum 316-320	420-9905	321470	630-690	1/2 sec	f 4	200	695	sn4b3spc	316-320	2"	1.8	2 mm	1	off
sn4_b3_spectrum 321-325	420-9905	321470	630-690	1/2 sec	f 4	200	700	sn4b3spc	321-325	2"	1.8	2 mm	1	off
sn4_b3_spectrum 326-330	420-9905	321470	630-690	1/2 sec	f 4	200	705	sn4b3spc	326-330	2"	1.8	2 mm	1	off
sn4_b3_spectrum 331-335	420-9905	321470	630-690	1/2 sec	f 4	200	710	sn4b3spc	331-335	2"	1.8	2 mm	1	off
sn4_b3_spectrum 336-340	420-9905	321470	630-690	1/2 sec	f 4	200	715	sn4b3spc	336-340	2"	1.8	2 mm	1	off
sn4_b3_spectrum 341-345	420-9905	321470	630-690	1/2 sec	f 4	200	720	sn4b3spc	341-345	2"	1.8	2 mm	1	off
sn4_b3_spectrum 346-350	420-9905	321470	630-690	1/2 sec	f 4	200	725	sn4b3spc	346-350	2"	1.8	2 mm	1	off
sn4_b3_spectrum 351-355	420-9905	321470	630-690	1/2 sec	f 4	200	730	sn4b3spc	351-355	2"	1.8	2 mm	1	off
sn4_b3_spectrum 356-360	420-9905	321470	630-690	1/2 sec	f 4	200	735	sn4b3spc	356-360	2"	1.8	2 mm	1	off
sn4_b3_spectrum 361-365	420-9905	321470	630-690	1/2 sec	f 4	200	740	sn4b3spc	361-365	2"	1.8	2 mm	1	off

Comments: 1) new (custom) filters from Omega Optical for NASA SDB contract.

2) This test to acquire data to correlate radiance to DN value as a function of input wavelength

3) Camera in LINEAR mode

4) GRATING #2 used for band 4, grating #1 for bands 1, 2 & 3 averaging 25 scans per reading on the ASD

5) ASD files stored in directory "FR/possys/000411/" on ASD #669

6) "order sorter" filter was switched at 680, so these samples taken twice; 350 nm filter used up through frame 300, then all frames after that taken with 620 order sorter filter in place

ADAR System Lab Test Sheet

Test of MTF using black/white edge target in hallway

Test Date
4/12/00

System under test
- ✱ 5500
- ☐ 3000
- ☐ 1000
- ☐ Other:______

Serial Number
SN4

FICAS SW version: 3.1.9
FOS SW version: 2.1
Test Site: NASA SSC
Test Personnel: Cody Benkelman, Thomas Nixon, Chris Schera

Filename	Band #	Camera Serial Numbers	Lens Serial Number	Spectral Band	Exposure Time	Aperture	ISO	Distance to edge target	FOCUS SET AT:		Hallway Lights (ON/OFF)	
sn4_mtf	1	420-9860	319268	450-515	1/15	f 2.8	200	75 meters	infinity		on	
file numbers	2	420-9903	319270	525-605	1/40	f2.8	200	75 meters	infinity		on	
016 through 040	3	420-9905	321470	630-690	1/20	f 4	200	75 meters	infinity		on	
four band images	4	420-9912	321697	750-900	1/30	f 5.6	200	75 meters	infinity		on	
sn4_mtf	1	420-9860	319268	450-515	1/15	f 2.8	200	75 meters	mark 1/2		on	BEST FOCUS (
file numbers	2	420-9903	319270	525-605	1/40	f2.8	200	75 meters	mark 1/2		on	BEST FOCUS (
041 through 065	3	420-9905	321470	630-690	1/20	f 4	200	75 meters	mark 1/2		on	
four band images	4	420-9912	321697	750-900	1/30	f 5.6	200	75 meters	mark 1/2		on	
sn4_mtf	1	420-9860	319268	450-515	1/15	f 2.8	200	75 meters	mark 1		on	
file numbers	2	420-9903	319270	525-605	1/40	f2.8	200	75 meters	mark 1		on	
66 through 91	3	420-9905	321470	630-690	1/20	f 4	200	75 meters	mark 1		on	

four band images	4	420-9912	321697	750-900	1/30	f 5.6	200	75 meters	mark 1		on	
sn4_mtf	1	420-9860	319268	450-515	1/15	f 2.8	200	75 meters	mark 2		on	
file numbers	2	420-9903	319270	525-605	1/40	f2.8	200	75 meters	mark 2		on	
92 through 116	3	420-9905	321470	630-690	1/20	f 4	200	75 meters	mark 2		on	BEST FOCUS (
four band images	4	420-9912	321697	750-900	1/30	f 5.6	200	75 meters	mark 2		on	
sn4_mtf	1	420-9860	319268	450-515	1/15	f 2.8	200	75 meters	mark 3		on	
file numbers	2	420-9903	319270	525-605	1/40	f2.8	200	75 meters	mark 3		on	
117 through 141	3	420-9905	321470	630-690	1/20	f 4	200	75 meters	mark 3		on	
four band images	4	420-9912	321697	750-900	1/30	f 5.6	200	75 meters	mark 3		on	
sn4_mtf	1	420-9860	319268	450-515	1/15	f 2.8	200	75 meters	mark 4		on	
file numbers	2	420-9903	319270	525-605	1/40	f2.8	200	75 meters	mark 4		on	
142 through 166	3	420-9905	321470	630-690	1/20	f 4	200	75 meters	mark 4		on	
four band images	4	420-9912	321697	750-900	1/30	f 5.6	200	75 meters	mark 4		on	
sn4_mtf	1	420-9860	319268	450-515	1/15	f 2.8	200	75 meters	mark 5		on	
file numbers	2	420-9903	319270	525-605	1/40	f2.8	200	75 meters	mark 5		on	
167 through 192	3	420-9905	321470	630-690	1/20	f 4	200	75 meters	mark 5		on	
four band images	4	420-9912	321697	750-900	1/30	f 5.6	200	75 meters	mark 5		on	
sn4_mtf	1	420-9860	319268	450-515	1/15	f 2.8	200	75 meters	mark 6		on	
file numbers	2	420-9903	319270	525-605	1/40	f2.8	200	75 meters	mark 6		on	

193 through 217	3	420-9905	321470	630-690	1/20	f 4	200	75 meters	mark 6		on		
four band images	4	420-9912	321697	750-900	1/30	f 5.6	200	75 meters	mark 6		on	BEST FOCUS (QUICK VISUA	
sn4_mtf	1	420-9860	319268	450-515	1/15	f 2.8	200	75 meters	mark 6		on	obviously out of focus, so	
file numbers	2	420-9903	319270	525-605	1/40	f2.8	200	75 meters	mark 6		on	these were not changed	
218 through 242	3	420-9905	321470	630-690	1/20	f 4	200	75 meters	mark 7		on		
four band images	4	420-9912	321697	750-900	1/30	f 5.6	200	75 meters	mark 7		on		

Comments: 1) This test recorded multiband images covering all four bands simultaneously; provided to Slawek Blonski as ERDAS .LAN format files.

2) new (custom) filters from Omega Optical for NASA SDB contract

3) Black/white edge target was paper, at end of hallway (approx. angle 7 degrees) illuminated with 3 x 500 watt lamps.

4) The focus set points were noted by counting marks made on the lens focusing ring (with exacto knife); "mark 1" is the first mark AFTER infinity, and "mark 1/2" is 1/2 way between infinity and the first mark.

Appendix G. OL Calibration Sphere Information

OL Calibration Sphere Information

OL Series 462 Automated Integrating Sphere Calibration Standard

INTRODUCTION

The OL Series 462 Automated Integrating Sphere Calibration Standard is designed for accurately calibrating microphotometers, image intensifiers, telephotometers, and imaging spectroradiometers. It is a large area, uniform, diffusely radiating source with a near normal luminance that can be varied over many decades without changing the color temperature. The OL Series 462 consists of a motorized source module (Optics Head) and a microprocessor controlled radiometer/power supply/motor controller (Controller). This enables remote location of either unit that facilitates alignment or positioning of the Optics Head with respect to the device to be calibrated.

The Optics Head is designed to accommodate integrating spheres having diameters of 4, 6, 8, 12, and 18 inches with exit (radiating) ports of 1, 1 ½, 2, 3, and 6 inches, respectively.

OL 462-X .... Luminance and Color Temperature
OL 462-X-.. Luminance, Color Temperature,
.... and Spectral Radiance (350-1100 nm)
OL 462-X-2.. Luminance, Color Temperature,
.... and Spectral Radiance (350-2500 nm)
OL 462-X-U .... Uncalibrated

"X" Designates diameter of integrating sphere.

OL SERIES 462 SOURCE MODULE (OPTICS HEAD)

Figure 1 shows the OL Series 462 Optics Head. The source is a 150-watt tungsten quartz-halogen reflectorized lamp. An automated, micrometer-controlled, variable aperture between the lamp and the entrance port of the integrating sphere enables continuous adjustment of the luminance over a range of 10^6. The sphere is coated with a highly reflective, diffuse coating to ensure high levels of uniform luminance.

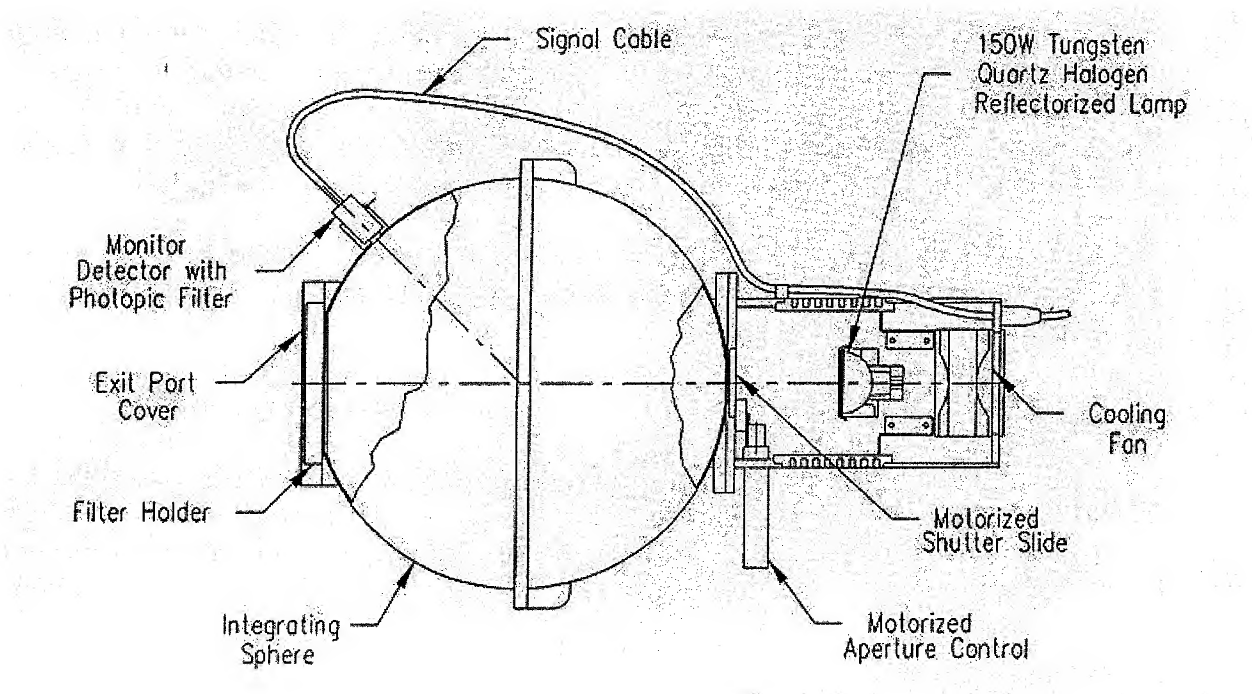


Figure 1.

A silicon detector-photopic filter combination with an accurate photopic response is mounted in the sphere wall and monitors the sphere luminance.

In addition to generating high levels of luminance, the in-line sphere concept with an intermediate spider baffle provides for exceptional near normal uniformity across the radiating aperture. A motorized shutter is located between the lamp and the entrance port of the integrating sphere. The location of the shutter ensures that any stray light (room light) entering the exit (radiating) port of the sphere is properly accounted for when zeroing the meter. A filter holder mounted at the exit port accommodates spectral shaping filters for simulation of various sources with color temperatures up to 6500K.

For calibrated units, a calibration certificate is provided stating the NIST traceable color temperature and luminance accuracy and the current for 2856K (See Calibration

Certificate). Spectral radiance values (optional) are provided for the OL 462-X-1 and OL 462-X-2. Table 1 gives tabular values of spectral radiance for a specified lamp current and luminance setting. The luminance setting should be adjusted using the motorized variable aperture (refer to the Operating Procedure section). In order to obtain relatively high levels of spectral radiance, the nominal color temperature for the spectral radiance calibration corresponds to approximately 3000K.

OL Series 462 Source Module (Optics Head) Specifications

Luminance Uncertainty (relative to NIST) .... ±2%
Spectral Radiance Calibration (relative to NIST) .... ±2-4%
350-1100 nm (OL Series 462-X-1)
350-2500 nm (OL Series 462-X-2)
Color Temperature Range .... 2000 to 3000K
Color Temperature Uncertainty .... ±25K
Luminance Stability .... ±0.5% (after 15 minute warm up)
.... ±2% 100 hours of use or 1 year
Sphere Coating (Reflectance) .... >99% (350 to 1100 nm)
Sphere Luminance Monitor (Built In) .... High accuracy silicon detector
.... With filtered CIE photopic response
Shutter .... Motorized
Variable Aperture .... Motorized

Luminance Levels (Typical)

Model Number	Sphere Diameter	Exit Port Diameter	Uniformity	Maximum @ 2856K	Luminance @3000K	Minimum Luminance
OL 462-4	4"	1"	±0.5%	22,500 fL	35,000 fL	0.001 fL
OL 462-6	6"	1 ½"	±0.5%	10,000 fL	15,500 fL	0.001 fL
OL 462-8	8"	2"	±0.5%	5,500 fL	8,700 fL	0.001 fL
OL 462-12	12"	3"	±0.5%	2,500 fL	4,000 fL	0.001 fL
OL 462-18	18"	6"	±0.5%	650 fL	1,000 fL	0.001 fL

L 462 CONTROLLER

The microprocessor-based OL 462 Controller performs all the system, interface and monitoring functions. Measured values, target values, operational prompts, and other pertinent information are displayed on a 2 line x 20 character alphanumeric vacuum-fluorescent display. A 20 key keypad, rotary parameter adjust knob and main system power switch are located on the front panel for easy manual access to all system functions.

All system functions are also accessible via the computer interface(s).

In order to provide a direct readout of user-defined optical units, the monitor detector's calibration factors are automatically applied by the OL 462 Controller. The user-defined optical unit or ampere reading is displayed with 4½ digit resolution and is controlled by a motorized variable aperture and shutter which are located in the Optics Head. The Controller supplies and monitors the DC current to the lamp with a 0.001 ampere resolution. The Controller also computes the color temperature of the source and displays lamp current or color temperature over the range of 2000 to 3000K. The user-defined optical units, lamp current and color temperature can be set by the OL 462 Controller or by an external computer.

All calibration data (including calibration dates) are stored by the controller's microprocessor in non-volatile EEPROM for long term data integrity.

Lamp hours are monitored by the built-in real-time clock and displayed upon power-up to remind the user when calibration is due.

Ten memory locations are provided for the user to store frequently used current/luminance targets that can be quickly recalled with two key presses.

The OL 462 offers an RS-232C interface as a standard feature with RS-422 and a GPIB (IEEE-488) interfaces as options.

OL 462 Controller Specifications

Current Control Range .... 0.001 to 6.500 Amperes
.... Auto Ramp Up/Down
Current Control Uncertainty .... ±0.025%
Current Control Resolution .... 0.001 Amperes
Current Regulation .... ±0.01% for 10% line variation
Luminance Aperture Control .... < (0.025 * $\sqrt{LUMINANCE}$) fL
Luminance Display Range .... 0.001 to 50,000 fL
Luminance Display Resolution .... 4 ½ digits
Operating Temperature Range .... 15% C to 35% C
Lamp Current Temperature Regulation .... ±0.025% / 10° C
Operating Humidity Range .... 10% to 85% (non-condensing)
Power (user selectable) .... 115 or 230 VAC (60/50 Hz) ± 10%

TABLE 1.

OL 462-12-2, S/N: 99102008

Spectral Radiance Values *

Wavelength (nm)	Spectral Radiance (mW/sr cm² µm)	Wavelength (nm)	Spectral Radiance (mW/sr cm² µm)
300.0nm	1.870E-01	600.0nm	3.519E+01
	2.977E-01		3.673E+01
	4.420E-01		3.830E+01
	6.350E-01		3.984E+01
	8.891E-01		4.128E+01
350.0nm	1.210E+00	650.0nm	4.307E+01
	1.605E+00		4.451E+01
	2.104E+00		4.589E+01
	2.683E+00		4.722E+01
	3.369E+00		4.848E+01
400.0nm	4.179E+00	700.0nm	4.967E+01
	5.167E+00		5.079E+01
	6.233E+00		5.176E+01
	7.379E+00		5.270E+01
	8.622E+00		5.359E+01
450.0nm	9.992E+00	750.0nm	5.431E+01
	1.148E+01		5.484E+01
	1.294E+01		5.564E+01
	1.444E+01		5.629E+01
	1.604E+01		5.689E+01
500.0nm	1.765E+01	800.0nm	5.748E+01
	1.933E+01		5.798E+01
	2.108E+01		5.837E+01
	2.282E+01		5.879E+01
	2.455E+01		5.921E+01
550.0nm	2.630E+01	850.0nm	5.964E+01
	2.809E+01		6.003E+01
	2.989E+01		6.047E+01
	3.167E+01		6.090E+01
	3.344E+01		6.129E+01

Measurements Performed By: CEA/DNG 4 RCS

* Lamp Current: 5.569 A
Luminance: 5986 fL
1/ Integrated Radiance (300 nm to 2500 nm) Setting: 0.6610E+02 mW/sr cm²
Calibration Factor - Integrated Radiance Response: 2.118E-06 A/(mW/sr cm²)
Two Additional Detector Ports: $BaSO_4$ - Plugs Installed

1/ The integrated radiance should be adjusted using the motorized variable aperture (refer to the *Operating Procedure* section).

Project No: 905-824
Date: September 20, 1999

TABLE 1. (Continued)

OL 462-12-2, S/N: 99102008

Spectral Radiance Values *

Wavelength (nm)	Spectral Radiance (mW/sr cm² µm)	Wavelength (nm)	Spectral Radiance (mW/sr cm² µm)
900.0nm	6.164E+01	1200.0nm	5.423E+01
	6.195E+01		5.336E+01
	6.222E+01		5.276E+01
	6.246E+01		5.205E+01
	6.266E+01		5.169E+01
950.0nm	6.283E+01	1250.0nm	5.140E+01
	6.297E+01		5.089E+01
	6.308E+01		5.056E+01
	6.316E+01		5.007E+01
	6.321E+01		4.954E+01
1000.0nm	6.322E+01	1300.0nm	4.898E+01
	6.330E+01		4.806E+01
	6.331E+01		4.699E+01
	6.310E+01		4.597E+01
	6.282E+01		4.469E+01
1050.0nm	6.260E+01	1350.0nm	4.246E+01
	6.217E+01		4.047E+01
	6.178E+01		4.097E+01
	6.140E+01		4.090E+01
	6.099E+01		4.046E+01
1100.0nm	6.044E+01	1400.0nm	3.943E+01
	5.962E+01		3.878E+01
	5.887E+01		3.800E+01
	5.866E+01		3.747E+01
	5.854E+01		3.695E+01
1150.0nm	5.828E+01	1450.0nm	3.663E+01
	5.792E+01		3.631E+01
	5.773E+01		3.585E+01
	5.813E+01		3.562E+01
	5.708E+01		3.547E+01

* Lamp Current: 5.569 A

Luminance: 5986 fL

1/ Integrated Radiance (300 nm to 2500 nm) Setting: 0.6610E+02 mW/sr cm²

Calibration Factor - Integrated Radiance Response: 2.118E-06 A/(mW/sr cm²)

Two Additional Detector Ports: $BaSO_4$ - Plugs Installed

1/ The integrated radiance should be adjusted using the motorized variable aperture (refer to the *Operating Procedure* section).

Project No: 905-824
Date: September 20, 1999

TABLE 1. (continued)

OL 462-12-2, S/N: 99102008

Spectral Radiance Values *

Wavelength (nm)	Spectral Radiance (mW/sr cm² μm)	Wavelength (nm)	Spectral Radiance (mW/sr cm² μm)
1500.0nm	3.535E+01	1800.0nm	2.046E+01
	3.515E+01		1.953E+01
	3.483E+01		1.885E+01
	3.448E+01		1.838E+01
	3.397E+01		1.769E+01
1550.0nm	3.357E+01	1850.0nm	1.737E+01
	3.302E+01		1.665E+01
	3.241E+01		1.573E+01
	3.181E+01		1.573E+01
	3.142E+01		1.541E+01
1600.0nm	3.097E+01	1900.0nm	1.474E+01
	3.048E+01		1.475E+01
	2.996E+01		1.468E+01
	2.949E+01		1.463E+01
	2.910E+01		1.455E+01
1650.0nm	2.864E+01	1950.0nm	1.444E+01
	2.801E+01		1.425E+01
	2.747E+01		1.402E+01
	2.760E+01		1.370E+01
	2.774E+01		1.329E+01
1700.0nm	2.701E+01	2000.0nm	1.286E+01
	2.568E+01		1.209E+01
	2.502E+01		1.151E+01
	2.511E+01		1.094E+01
	2.514E+01		1.043E+01
1750.0nm	2.465E+01	2050.0nm	9.905E+00
	2.357E+01		9.438E+00
	2.278E+01		8.973E+00
	2.239E+01		8.550E+00
	2.159E+01		8.164E+00

* Lamp Current: 5.569 A
Luminance: 5986 fL
1/ Integrated Radiance (300 nm to 2500 nm) Setting: 0.6610E+02 mW/sr cm²
Calibration Factor - Integrated Radiance Response: 2.118E-06 A/(mW/sr cm²)
Two Additional Detector Ports: $BaSO_4$ - Plugs Installed

1/ The integrated radiance should be adjusted using the motorized variable aperture (refer to the *Operating Procedure* section).

Project No: 905-824
Date: September 20, 1999

TABLE 1. (Continued)

OL 462-12-2, S/N: 99102008

Spectral Radiance Values *

Wavelength (nm)	Spectral Radiance (mW/sr cm² µm)	Wavelength (nm)	Spectral Radiance (mW/sr cm² µm)
2100.0nm	7.765E+00	2400.0nm	4.229E+00
	7.494E+00		4.093E+00
	7.233E+00		3.957E+00
	7.019E+00		3.864E+00
	6.917E+00		3.762E+00
2150.0nm	6.906E+00	2450.0nm	3.689E+00
	6.952E+00		3.660E+00
	7.083E+00		3.555E+00
	7.258E+00		3.484E+00
	7.606E+00		3.376E+00
2200.0nm	8.132E+00	2500.0nm	3.346E+00
	8.414E+00		
	8.283E+00		
	8.021E+00		
	7.827E+00		
2250.0nm	7.644E+00		
	7.441E+00		
	7.215E+00		
	6.983E+00		
	6.817E+00		
2300.0nm	6.438E+00		
	6.012E+00		
	5.660E+00		
	5.390E+00		
	5.176E+00		
2350.0nm	4.971E+00		
	4.865E+00		
	4.716E+00		
	4.526E+00		
	4.362E+00		

* Lamp Current: 5.569 A
Luminance: 5986 fL
1/ Integrated Radiance (300 nm to 2500 nm) Setting: 0.6610E+02 mW/sr cm²
Calibration Factor - Integrated Radiance Response: 2.118E-06 A/(mW/sr cm²)
Two Additional Detector Ports: $BaSO_4$ - Plugs Installed

1/ The integrated radiance should be adjusted using the motorized variable aperture (refer to the *Operating Procedure* section).

Project No: 905-824
Date: September 20, 1999

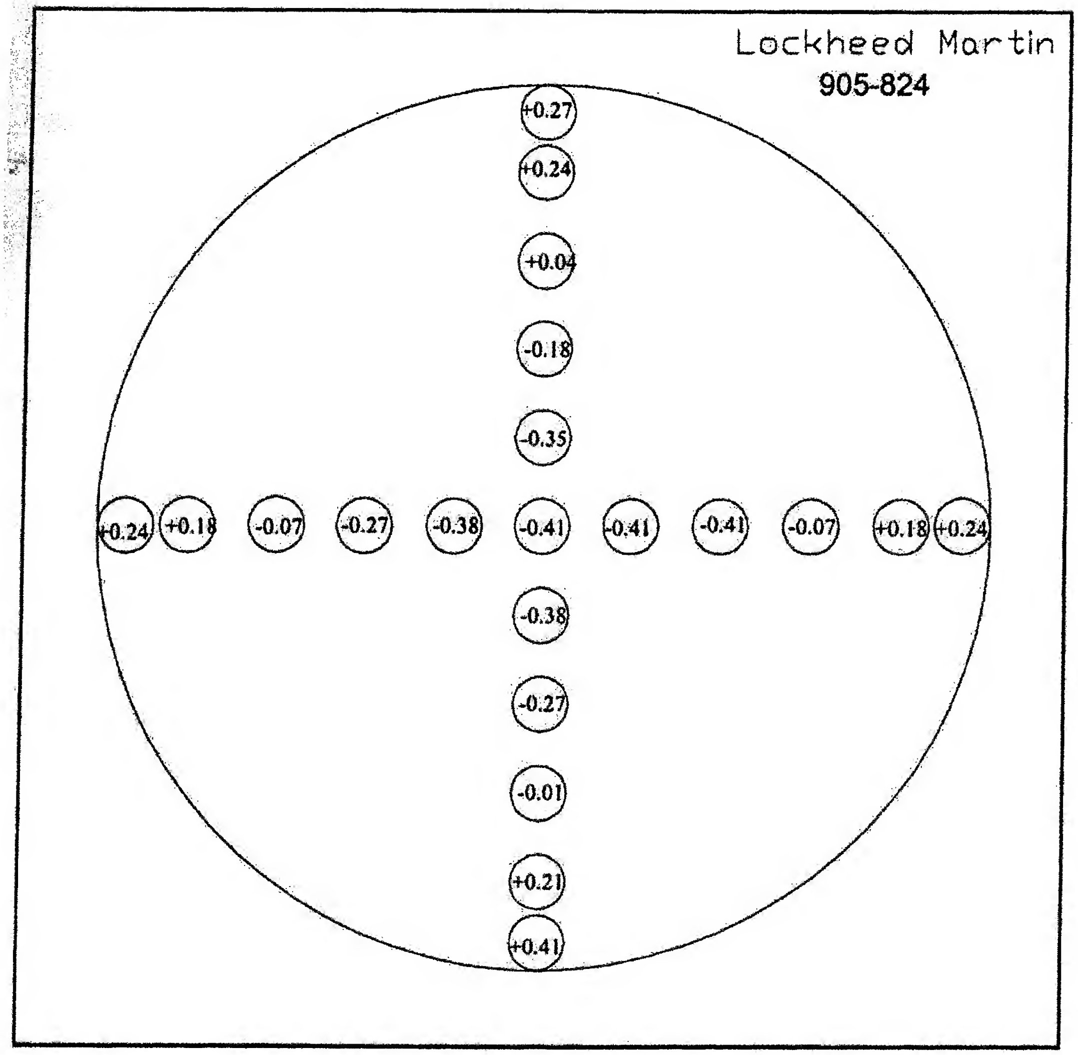


Figure 34. Sphere exit port axial luminance distribution.

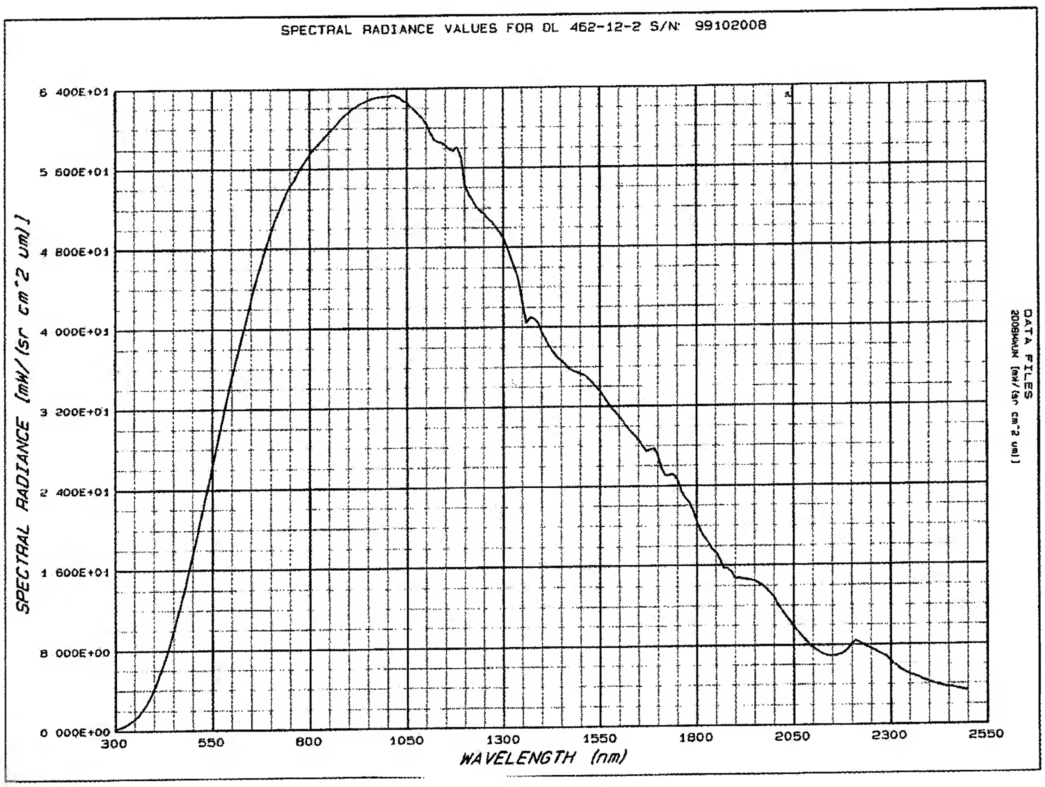


Figure 35. Cal sphere radiance curve.

Appendix H. Overview of Image Formation Process and Relationship to Point Spread Function

The system model can be given as follows. Let a point source in the target scene be represented by a set of delta functions. An image is formed as a result of convolution of PSF with the input scene:
object, input the is
image, the is where

$$I_i(x,y) = \int_{-\infty}^{\infty}\int I_o(x,y) PSF(x-x_o, y-y_o)dx_o dy_o \qquad 1$$

where $I_I(x,y)$ is the image,
$I_o(x,y)$ is the input object

The PSF is the system's impulse response and is assumed to be a slow varying function with position. In real optical systems, perspective and optical aberration depend upon field angle, but over small field angles, the optical system can be assumed to be spatially invariant. Although we are interested in PSF, practical considerations force us to examine targets other than point sources. A common target to use is an edge. An edge has all spatial frequencies and its derivative is the LSF. We examine slices of *PSF(x,y)*, with LSF.

$$l(x) = \int_{-\infty}^{+\infty} PSF(x', y')dy' \qquad 2$$

Where *l(x)* is the LSF. LSF can be used as a measure of spatial resolution by measuring its Full Width at Half the Maximum (FWHM).

Next we investigate the relationship between the edge response and LSF. Taking the derivative of the edge response with respect to across-track or along-track results in the LSF in that direction. To compute the LSF, the edge response should be obtained from a well-sampled edge target image. With classical cross section sampling, few samples from the edge can be obtained. To improve the sampling rate, we can take advantage of the tilted edge and sample in the vertical or horizontal directions, as different pixels are different fractions of a pixel from the edge.

Denoting θ to be the angle between the scan line and edge and GSD is the Ground Sample
Distance, then the sample distance Δx is

$$\Delta x = GSD \times \tan\theta \qquad 3$$

We now determine the sample across the edge by stepping nearly parallel to edge. The edge response can be obtained by plotting the pixel value vs. Δx. This is shown in Figure 36. Note that classical cross section sampling results in inaccurate edge response, due to undersampling.

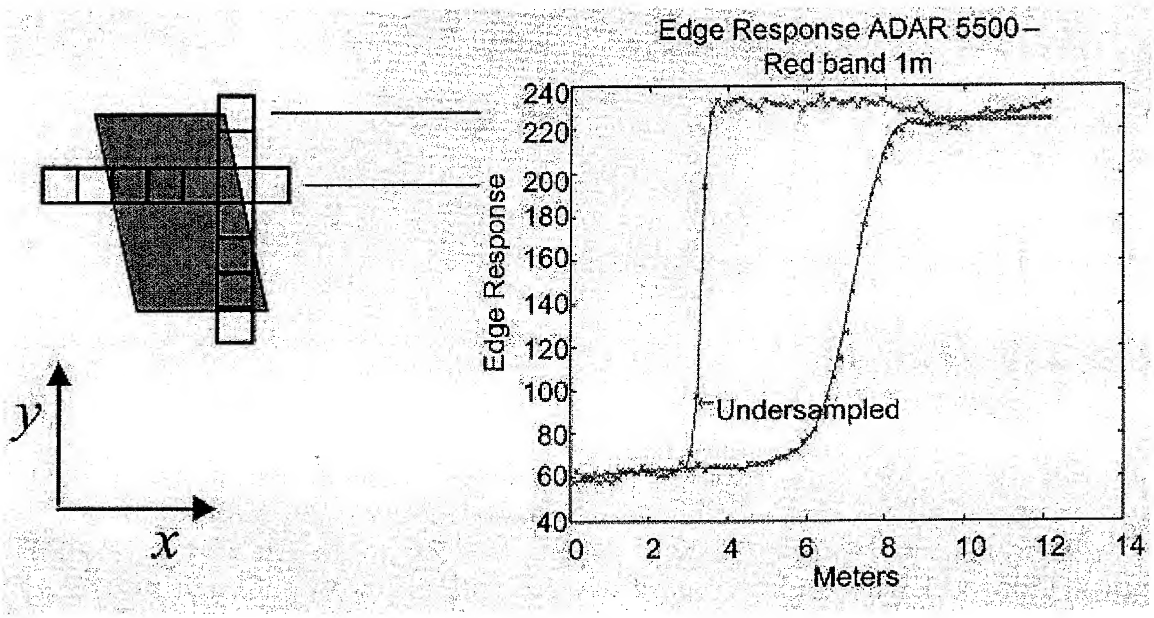


Figure 36. Edge response.

Computing the Line Spread Function from the Edge Response and Determining the Spatial Resolution

To obtain LSF for measuring the spatial resolution, we take the derivative of the edge response. This operation will give the maximum rate of increase per unit distance. Defining *E(x)* to be the edge response, then along the scan line, LSF can be obtained as follows:

$$E(x) = \int_{-\infty}^{x} l(a)da \qquad \textbf{4}$$

$$l(x) = \frac{d}{dx}E(x) \qquad \textbf{5}$$

Although there are many methods of defining spatial resolution, we will use the Full Width at Half Maximum (FWHM) of the LSF. A sample LSF is shown in Figure 37.

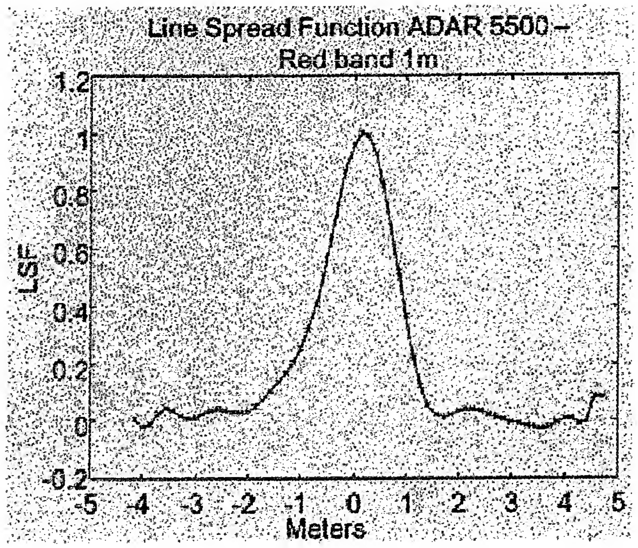


Figure 37. Line spread function.

Modulation Transfer Function and Frequency Domain Analysis

The Modulation Transfer Function (MTF) is the response of the system in frequency domain and therefore, it is a measure of an imaging system's ability to recreate the spatial frequency content of the scene. By taking the Fourier transform of the Line Spread Function or Point Spread Function and computing the magnitude, MTF is obtained:

$$MTF(\beta,\gamma) = FT[PSF(x,y)] \qquad \textbf{6}$$

Where **b** and **g** are spatial frequencies. The Fourier Transform of LSF yields an MTF profile along a single axis.

$$MTF(\beta,0) = FT[l(x)] \qquad \textbf{7}$$

Appendix I. Acton Research Corporation SpectraPro-500i

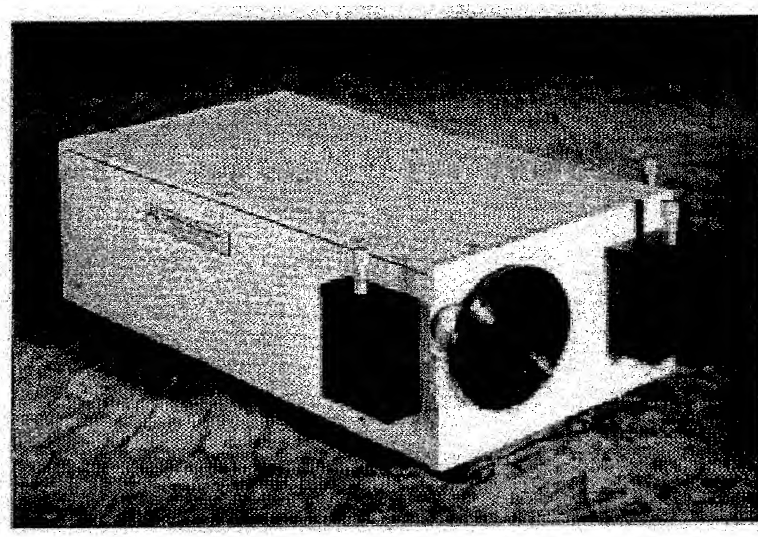


Figure I-1. ARC SpectraPro-500i single monochromator.

ARC SpectraPro-500i 0.500 Meter Focal Length Triple Grating Imaging Mono-chromator / Spectrograph SN#500104

Every SpectraPro-500i monochromator or spectrograph includes a triple grating turret for 1, 2, or 3 gratings, imaging optical system, 32-bit microprocessor controlled scanning, built-in RS232 and IEEE488 interfaces, and micrometer controlled entrance slit (optional second entrance slit available).

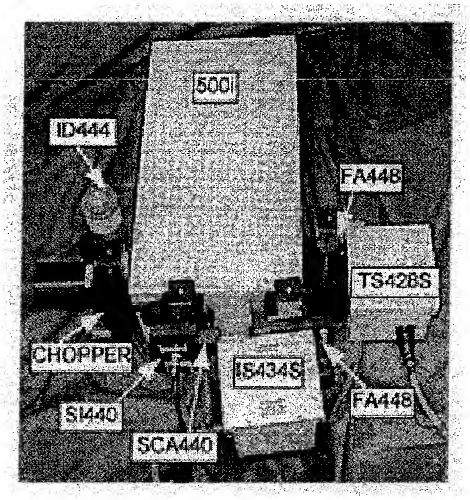


Figure I-2. ARC SpectraPro-500i components.

Per customer specifications, this instrument is supplied with the following accessories:

1. Four motorized slits attached to the entrance and exit ports
2. TS-428 Tungsten light source
3. IS-434 IR light source
4. Two FA-448 filter wheels
5. SCA-440 source compensation module
6. SI-440 silicon detector
7. ID-442 PbS detector
8. ID-444 M-C-T detector

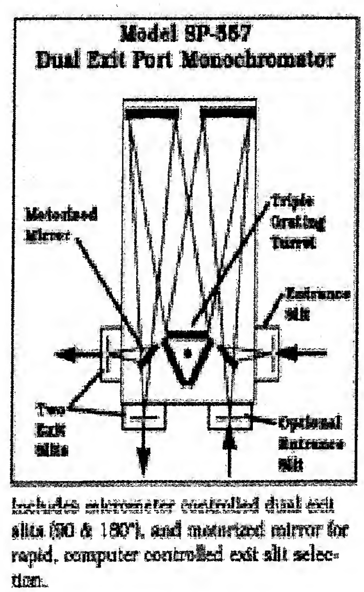


Figure I-3. ARC SpectraPro-500i internal configuration and path.

ARC SpectraPro-500i Monochromator – Technical Specifications (1200g/mm grating).

Focal length	500mm
Aperture Ratio	f/6.5 (68x68mm gratings)
Optical Design	Imaging Czerny-Turner
Mirrors	Polished Aspheres
Optical Paths	90° std, 180° opt
Scan Range	0 to 1400nm mechanical range
Operating Range	185nm to FIR
Resolution	0.05 nm @ 435.8nm
Dispersion	1.7nm/mm (nominal)
Accuracy	±0.2nm
Repeatability	±0.05nm
Drive Step Size	0.0025nm (nominal)
Focal Plane Size	27mm x 14mm
CCD Focus	o-ring sealed sliding tube w/ 3-point adjustment
Detector Coverage	~42.5nm on 1" focal plane
Standard Slits	10μm to 3mm wide, 4 & 14mm high
Slit Adjustment	Micrometer
Grating Mount	Triple grating turret for 1, 2, or 3 gratings
Interchangeable Turrets	Optional
Grating Change Time	< 20 seconds
Grating Drive System	32-bit microprocessor direct digital scanning
Scan Linearity	Wavelength
Size	21" long x 11" wide x 8" high
Optical Axis Height	4.875"
Weight	40 lbs.

This SpectraPro is supplied with two kinematically mounted triple grating turret assemblies that are interchangeable in the SpectraPro without realignment.

Turret I contains the following 3 gratings:

Position I: 1800 G/mm @ 500nm
Position 2: 600 G/mm @ 1μm
Position 3: 300 G/mm @ 2μm

Appendix J. . Analytical Spectral Devices FieldSpec FR

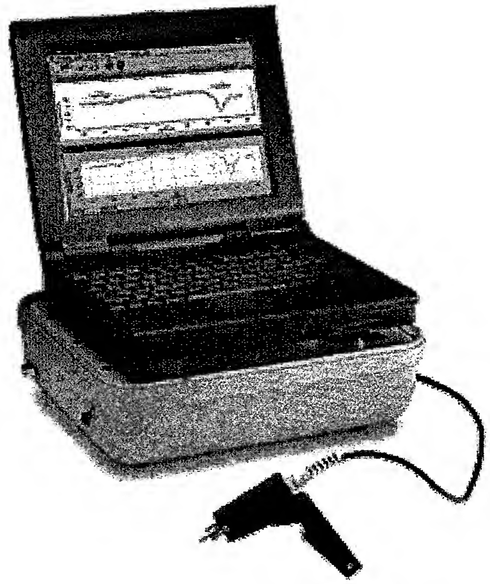


Figure J-1. ASD FSFR Spectroradiometer.

ASD FSFR Spectroradiometer SN#1017

At less than 8 kg, FieldSpec FR is a truly portable field spectroradiometer. A 0.35-2.5 µm spectral range, 10 nm spectral resolution, and speed of 10 spectra per second provide versatility not available in other instruments. One may easily configure FieldSpec to rapidly collect many spectra or select the scan averaging mode and collect fewer, high signal-to-noise, spectra. A variety of available fore-optics are available to customize FieldSpec to specific applications. The FieldSpec translates measurements into instant feedback: continuous real-time display on the notebook computer's LCD screen. The FieldSpec's intuitive graphical interface allows for easy configuration and control of the instrument. The FieldSpec FR spectroradiometer combines three spectrometers to cover the entire solar reflected portion of the spectrum, 350 to 2500 nm. A photo diode array spectrometer is used to cover the 350 to 1000 nm spectral range (UV/VNIR), while two fast scanning spectrometers provide coverage for the wavelength range from 1000 to 2500 nm (SWIR 1 and 2). The UV/VNIR detector is a 512 element low dark current NMOS photo diode array operated at ambient temperature. Single element InGaAs detectors, thermoelectrically cooled, are used in the two SWIR spectrometers. All three spectrometers utilize concave holographic grating as the wavelength dispersing elements. The light input to the FieldSpec FR's spectrometers is through a fiber optic bundle, 1.2 meters in length. While the use of longer fiber optic cables is possible, the performance will be degraded at wavelengths beyond 2200 nm. The optical fibers carrying the light to the spectrometers are packaged as a single bundle exterior to the instrument. Once inside the instrument, the fibers are

separated into three bundles which then deliver the collected light to each of the three spectrometers. The common probe end has a 25° field-of-view and may be fed through the included tripod mountable pistol grip.

All FieldSpec models come complete with the following standard features:

- Fiber optic cable input, 1.2 meters in length with 25° full angle cone of acceptance field-of-view.
- Built-in sub notebook computer with AC/DC adapter-charger, battery, hard disk drive, and floppy disk drive.
- Spectrometer Computer Interface: Bi-Directional Parallel Port.
- Spectrometer battery pack with fanny pack battery belt and harness.
- User interface software with pull-down menus and easy-to-use screens.
- Software for data acquisition and storage of Raw DN, reflectance, radiance and irradiance measurements.
- Real-time calculations of reflectance.
- Real-time display of Raw DN or reflectance spectra.
- Real-time spectrum averaging for up to 31,800 spectra for increased signal-to-noise.
- Post processing file structure for radiance and irradiance calculations and display.
- 16 bit encoding. 12 bit for CCD units.
- Offset correction with built-in shutter and automatic offset subtraction.
- Automatic time stamp in spectral file headers and automatic spectral file extension assignments.
- Pistol grip that can be mounted on a tripod.
- Users manual
- 1 year limited warranty

The other accessories obtained from ASD are:

- 1°, 5°, 8°, & 18° foreoptics
- Cosine receptor
- Additional batteries
- AC/DC adapter/charger
- 99% reflectivity Spectralon panel
- ASD laboratory radiometric calibration files

Performance specifications for the FieldSpec FR spectroradiometer:

- Spectral range: 350 - 2500 nm
- Sensors: One 512 element photo diode array and two thermoelectrically cooled, "graded index", extended range
- InGaAs photodiodes
- Sensor linearity: +/-1%
- Dispersion elements: One fixed and two fast scanning holographic reflective gratings.
- Sampling interval: 1.4 nm for 350 - 1000 nm, 2 nm for 1000 - 2500 nm.
- Spectral resolution: 3 nm @ 700 nm, 10 nm @ 1500 nm, and 10 nm @ 2100 nm.

- Number of channels: The FieldSpec FR spectroradiometer is preset to record data using the best possible
- resolution for the entire spectrum. For the entire region 350 - 2500 nm there are 1512 channels prior to
- interpolation. The user may adjust the spectrum viewing parameters, such as the axis configuration, to suit their
- needs. Also, the user may use the mouse operated "rubber band" zoom-in feature. Continuous spectra are displayed
- in real-time on the LCD for raw DN or reflectance. Radiance and irradiance spectra may be displayed in post
- processing.
- Wavelength accuracy: +/-1 nm.
- Wavelength Repeatability: Better than +/-0.3 nm with +/-10° C of calibration temperature.
- Scan time: A new spectrum is generated every 0.1 seconds for the entire spectral range.
- Data storage: Data are stored in binary form on the built-in hard disk drive.
- Dynamic range: Based on the responsivity of the FieldSpec FR spectroradiometer, maximum radiance values
- measurable by the FieldSpec FR are well in excess of twice those for a 0° solar zenith angle and a 100%
- reflectance Lambertian panel. The responsivity was determined by viewing a stable, NIST traceable, radiance
- source with the FieldSpec FR.
- Second order effects: The FieldSpec FR spectroradiometer has three spectrometers. The first spectrometer,
- covering from 350 to 1000 nm, is based on a 512 element photodiode array. Because the wavelength coverage of
- this spectrometer is more than one octave, a multi-element order sorting filter is mounted on top of the detector
- array. This filter prevents second order (and higher) diffracted light from reaching the detector. The second and
- third spectrometers, covering from 1000 to 1800 nm and from 1800 to 2500 nm respectively, cover a wavelength
- range that is less than one octave. The detector in each spectrometer has a long pass filter, with wavelength
- cut-ons of 980 nm and 1750 nm respectively, to prevent any second (or higher) order diffracted light from reaching
- the detector.
- Operational weight: 7 kg + 2.2 kg battery pack.
- Operational size: 35 x 29 x 13 cm.

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*
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1. REPORT DATE *(DD-MM-YYYY)* 29-01-2003	2. REPORT TYPE		3. DATES COVERED *(From - To)*
4. TITLE AND SUBTITLE NASA Scientific Data Purchase Laboratory Characterization of Positive Systems ADAR 5500 SensorL SN4 Report			5a. CONTRACT NUMBER NAS13-650
			5b. GRANT NUMBER
			5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Slawomir Blonski			5d. PROJECT NUMBER
			5e. TASK NUMBER
			5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Lockheed Martin Space Operations			8. PERFORMING ORGANIZATION REPORT NUMBER SE-2003-01-00006-SSC
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Earth Science Applications Directorate			10. SPONSORING/MONITOR'S ACRONYM(S)
			11. SPONSORING/MONITORING REPORT NUMBER
12. DISTRIBUTION/AVAILABILITY STATEMENT Publicly Available STI per form 1676			
13. SUPPLEMENTARY NOTES URL - http://www.esa.ssc.nasa.gov			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19b. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Slawomir Blonski
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	110	(228) 688-1944